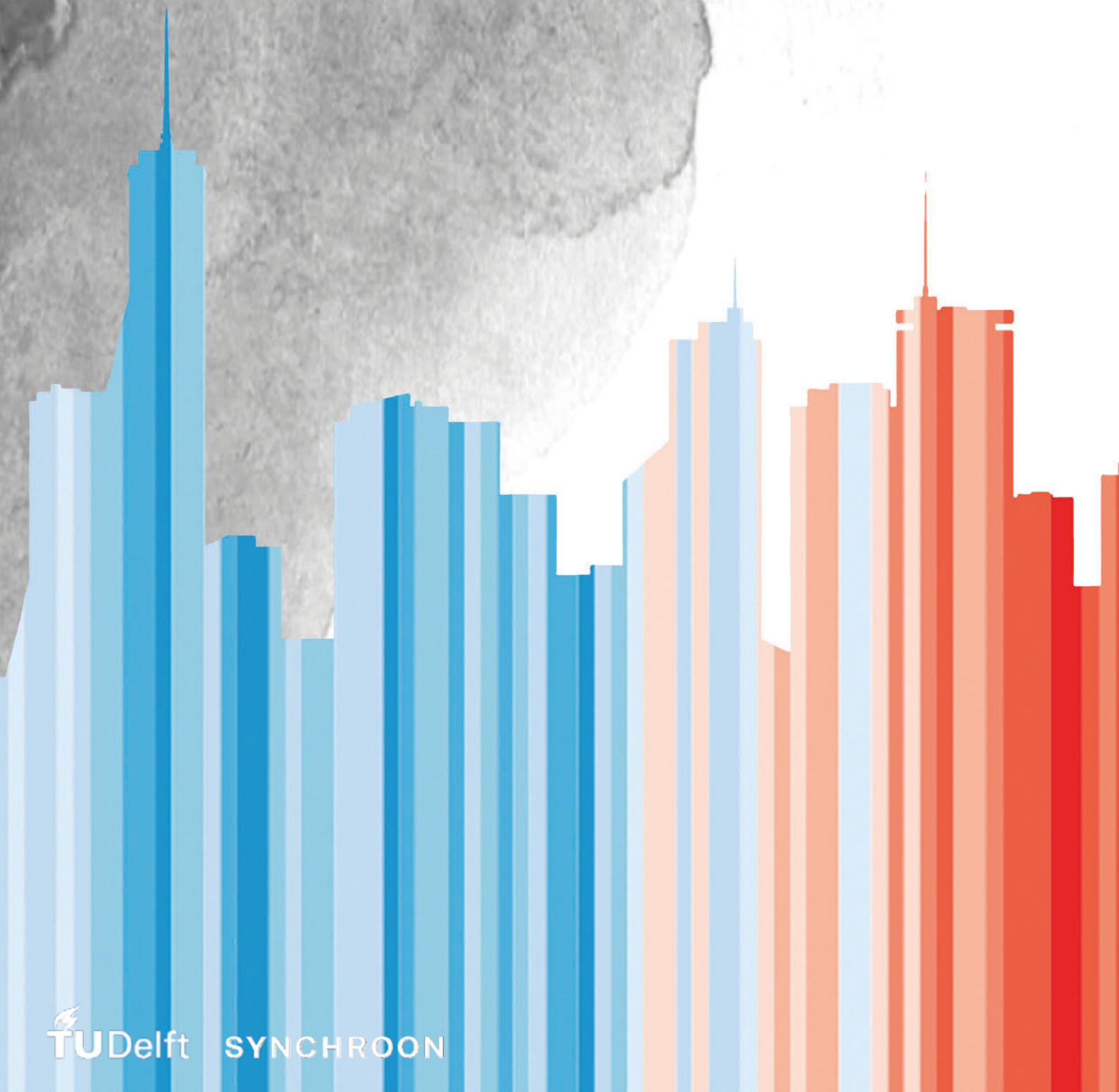
The developer as low-emission supply chain initiator.

A multiple-case study examining the supply-chain configuration and the developer's role in implementing low-emission construction practices in Dutch inner-city high-rise projects.



TU Delft SYNCHROON

Colophon

Author

Name	Mr. J.J.F. (Jelmar) Broekman
Student number	4647963

Education	
Institution	Delft University of Technology
Faculty	Architecture and the Built Environment
Master	Architecture, Urbanism & Building Sciences
Master track	Management in the Built Environment
Scientific domain	Design and Construction Management
Date	11.01.2024
Version	P5

Thesis Supervisors

First Mentor	Dr. R (Ruben) Vrijhoef Design & Construction Management (MBE)
Second Mentor	Dr. S (Stijn) Brancart Structural Design (AE&T)

Graduation Company

Company	Synchroon
Company Supervisors	J. (Jochem) Joosten Cost Expert ir. M. (Maaike) Perenboom Real estate developer & Circular strategist

Preface

From the moment I began my architecture bachelor in 2017 until now I have experienced a shift in interest from the product towards the process. A building is often not something that can be ordered from a catalogue, but it is the result of a process in which many internal and external stakeholders together influence the final product. No one is in full control of the lengthy process and therefore the responsibility of transitioning towards a more sustainable sector is a complicated task.

The government depends on private organizations in the construction industry to fight the housing crisis in the Netherlands, while at the same time limiting emissions in the process of building those houses. Since there is an urgency to these two problems my interest went out to the possibilities market parties already have today and how these can be applied tomorrow. Out of all the organizations that form the construction supply chain together, I decided to focus on the role of the project developer. While the developer isn't naturally seen as one of the most environmentally concerned stakeholders, the position between the demand and supply side in the construction process makes it an interesting starting point for the transition towards low-emission processes.

I would like to thank my graduation company Synchroon for offering me the possibility to experience the dynamics of working at a project developer during my graduation. It was valuable to develop my thesis in an environment where realism and experience meet low-emission ambition and a front-runner's mentality. Especially discussions and conversations with my tutors Jochem Joosten and Maaike Perenboom have helped me gain new insights and develop the message.

Although the process wasn't always easy, being part of a bigger research project and working at a graduation company have made it feel like teamwork. For this, I also want to thank my tutors at the TU Delft; Ruben Vrijhoef, Stijn Brancart and Peter Koljensic for their support throughout the graduation process. All three of them showed enthusiasm about the topic and I could easily reach out to them whenever I needed advice. Our meetings boosted my confidence and always provided interesting new insights, which contributed to the learning experience it has been.

I hope that the result can create mutual understanding between both public and private organizations in their way towards an emission-free construction industry!

Sincerely,

Jelmar Broekman

Rotterdam
January, 2024

Abstract

The construction industry is responsible for the emitting carbon, nitrogen, and particulate matter, which is harmful to the environment and contributes to global warming. Municipalities in the Netherlands plan to reduce emissions in inner-city developments to zero before 2030, for which a transformation of the already complicated construction supply chain would be necessary. The unique characteristics of the construction supply chain; temporary coalition of organizations working on one-of-a-kind projects, complicate reduction of supply chain emissions. In other sectors like manufacturing focal firms take in a central position between the demand and supply system and can align the supply chain. In construction the developer translates demands from society, the public and customers into projects that are executed by core supply chain stakeholders. The main question to be answered in this thesis is: *How can real estate developers organize a low-emission supply chain for high-rise construction in Dutch cities?* A literature review on green construction supply chain management and construction emissions have given insight into the drivers, barriers, and roles of different stakeholders in low-emission design, -procurement, -logistics and -construction & manufacturing. Inner-city high-rise case studies and semi-structured interviews with relevant stakeholders within these projects were conducted to draw lessons from practice. Developers can have a big influence on construction emissions through setting ambitions and translating these low-emission ambitions in the criteria for the procurement of services and materials for all supply chain stakeholders. In design, close collaboration with the architect and early involvement of the contractor and relevant expertise can help implement low-emission practices. Logistics and construction & manufacturing emissions can be influenced through contractual agreements with contractors, subcontractors, and suppliers, but should not be a direct responsibility of the developer and ask for active involvement of the government.

KEYWORDS – Low-emission Construction, Logistics, Construction & manufacturing, Procurement, Green Supply Chain Management, Multiple case-study, Real estate Developer, Inner-city high-rise Construction

Executive Summary

Introduction

Over recent decades, human activities have put immense pressure on our planet's habitability, necessitating industry-wide transitions to curb harmful emissions. The construction sector stands out as a major emitter of greenhouse gases, nitrogen, and particulate matter, contributing 37% of global carbon emissions (UNEP, 2022) activities and materials production collectively account for 9% of total CO2 emissions worldwide, with a quarter of carbon emissions stemming from the use and operation of built environments (UNEP, 2022).

While facing environmental challenges, the construction sector fights societal issues like the housing shortage in the Netherlands' G4 cities. Collaborating with academic institutions and market stakeholders, these cities embark on a research project focusing on sustainable criteria for inner-city high-rise buildings (AMS, n.d.). Since dwellings are built by private organizations in the Netherlands, the government will need to collaborate with market parties.

For the transition towards low-emission construction process changes should take place across different points in the construction supply chain and it is important that stakeholders start collaborating closer together (Karlsson et al., 2020; Venås et al., 2020). This can be a complicated process, since the unique characteristics of the supply chain form barriers in the transition towards more green construction practices (Badi & Murtagh, 2019). Some article stipulate the need for a shared pathway that can be coordinated nationally or internationally and the need for more practical outcomes (Badi & Murtagh, 2019; Karlsson et al., 2020).

Another literature review on Green supply chain management explains the research gap in the collection of relational factors and soft parameters between stakeholders in the process of realizing low-carbon construction (S. Kesidou & Sovacool, 2019). The developer takes in an important position between political demand and market execution and can therefore play an important role in leading low-emission transition in the construction supply chain (Badi & Murtagh, 2019; Heurkens, 2020)

To find out how the collaboration between stakeholders can be improved to benefit the transition towards low-emission construction and the role real estate developers can have the following research question is formulated:

How can real estate developers organize a low-emission supply chain for high-rise construction in Dutch cities?

In order to answer the main question, the following sub questions will be answered first

1. How can emissions related to the construction process for high-rise construction in Dutch cities be minimized throughout the supply chain?
2. What actors internal and external to the supply-chain influence the implementation of low-emission practices for high-rise construction in Dutch cities?

3. How are low-emission practices currently implemented in Dutch high-rise construction projects and what is still missing?
4. What drives or withholds different actors to implement low-emission practices for high-rise construction in Dutch cities?
5. What role can developers take in the implementation of low-emission practices for high-rise construction supply chains in Dutch cities?

Research objectives

The goal of this research is to provide insight to the relation between stakeholder collaboration in the construction supply chain and the effect this has on the implementation of low-emission practices in inner-city high-rise projects. Next to an academic contribution the goal of this research is to provide a practical steering framework for developers. The conclusions and recommendations should deliver a practical outcome for both governments and private organizations.

Methodology

The research is divided into three parts. First a theoretical basis will be created through literature search on the construction supply chain and green supply chain management, construction emissions and low-emission construction processes and roles and responsibilities of the real estate developer and other important supply chain stakeholders. After the theoretical research empirical research through exploratory interviews, in- depth interviews and a validation session. The in-depth interviews will be part of a case-study into four inner-city high-rise projects where low-emission practices are implemented. Findings of these case studies will be tested in an expert panel that exists off different industry stakeholders. After comparing empirical findings to the theoretical findings, conclusions can be drawn.

Theoretical and empirical research

Emissions in the supply chain can be limited through the implementation of low-emission practices. Low-emission design, Low-emission procurement, low-emission logistics, and low-emission end-of-life management can help to reduce emissions across the supply chain and stakeholders have different roles in the implementation of these practices. The most important stakeholders on the supply side are developers, contractors, subcontractors, suppliers, architects, and consultants. Municipalities and the national government are most influential on the demand side.

In the case study projects early involvement of contractors and relevant suppliers and subcontractors is seen as beneficial to the implementation of low-emission practices. Architects play an important role in integrating low-emission practices in the complete design. The developer is seen as an important initiator of low-emission ambitions since ambitions need to be clear from the start. These ambitions can then be used to involve parties with the right mindset and intrinsic motivation and the low-emission ambitions can become part of the contractual agreements between the supply chain partners. The use of a shared emission certificate, ceiling or calculation method is seen as tool to implement low-emission practices effectively across the supply chain.

It is not necessary or desirable for one party, like the developer to take over responsibility over the complete supply chain to achieve low-emission ambitions. Since, every stakeholder has their own

expertise, responsibility in the different life-cycle f=phases should be divided accordingly. The developer has the most significant influence in design and procurement. Low-emission logistics and construction & manufacturing can be coordinated better by the main contractor, but the developer can translate low-emission demands in the tender and selection documents for the contractor. The contractor translate these requirements to subcontractors and suppliers and the developer can guard the ambitions.

Conclusions

Managing a low emission supply chain can be done by implementing low emission practices (LEP) in design, procurement, construction, logistics and at the end-of-life. For example by reducing the amount of hazardous materials and replacing them with (lighter) bio-based materials and transporting them and processing and transporting them with fuel efficient or electric equipment and vehicles.

On the supply side of the construction supply chain for Dutch inner-city high-rise projects developers, architects and contractors play a central role in the implementation of LEP and suppliers, consultants and subcontractors play an important role depending on the selected innovation. On the demand side of the supply chain the municipality and national government have the most significant impact on the implementation of LEP by prescription of calculation tools and emission ceilings. Investors and insurance companies are required to show flexibility to innovation by reducing risk premiums and traditional standards.

Currently in the Dutch market, stakeholders focus on the national minimum (BENG, MPG, Aerius) and only a few stakeholders go a step further and try to meet the carbon goals in the Paris agreement. This is mainly translated into material selection criteria and doesn't affect the type of on-site equipment and transportation to and from the site much. Only few contractors are in the transition towards electrified construction sites, but none of the demand and supply side stakeholders seem to feel responsible for the reduction of logistics emissions.

In the absence of political drivers, which was the case in the case study projects, clear ambitions and the mindset of all supply chain stakeholders are the most important drivers for the implementation of LEP. The most important barriers are technological and financial limitations that come with innovative construction techniques.

The developer is in the position to set these ambitions and secure implementation in design. It is not desirable for the developer to take over full responsibility during construction from the contractor. Risk can best be spread according to expertise. By translating political and internal ambitions into a shared calculation method and emission ceilings and involving these in procurement criteria for all services and materials, the municipality and developers can secure implementation of LEP in later stages of the development process. The most important conclusions are summarized in figure 1 on the next page. A more elaborated explanation of figure 1 can be read on page 79 and 80.

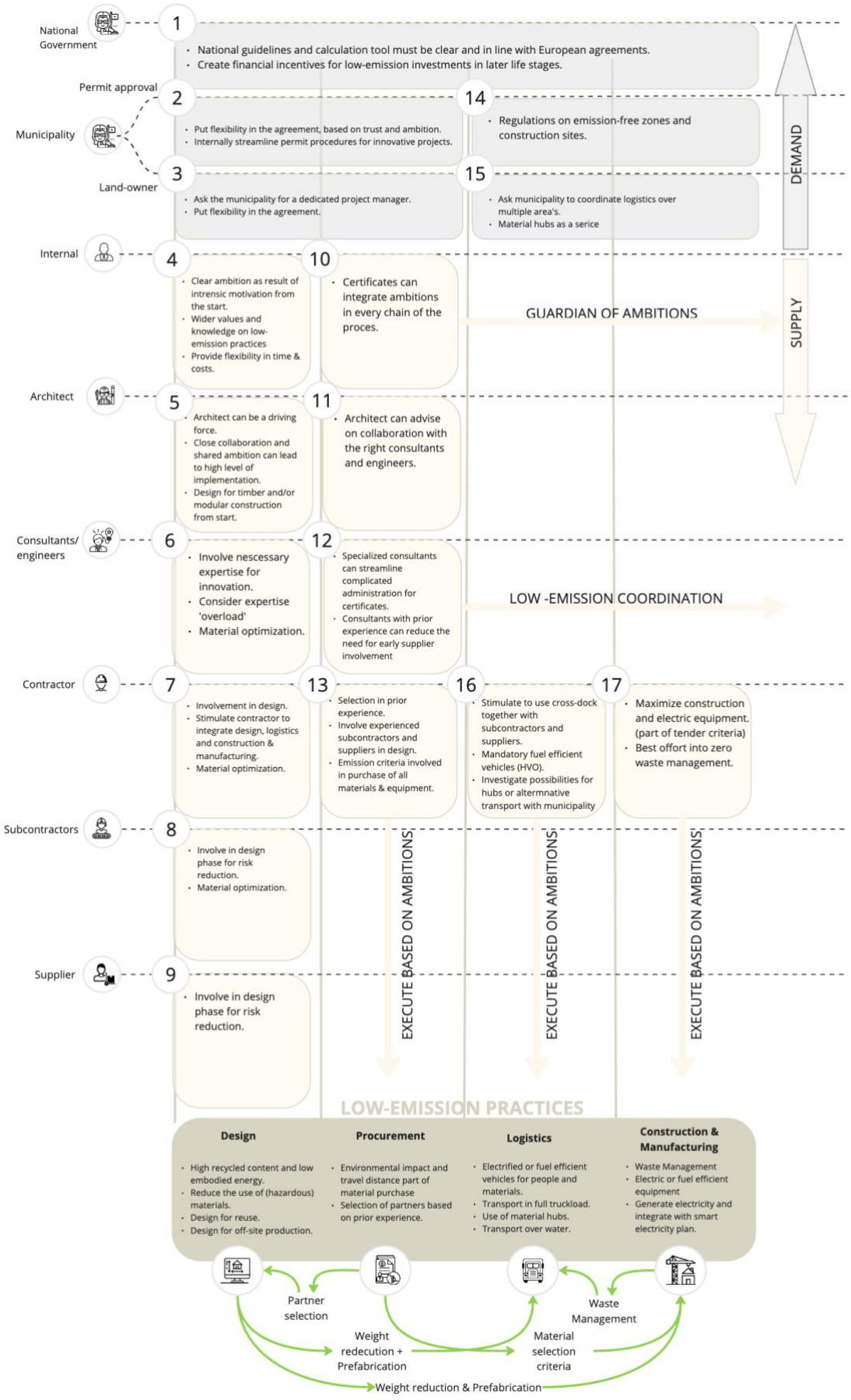


Figure 1, Conceptual Low-emission steering model for real estate developers (own illustration)

Content

1 Introduction.

Chapter 1 | Introduction

Problem statement

Over the past decades, it has become clear that the habitability of our planet is under pressure due to human activities. Processes across different industries must undergo transitions to limit the amount of harmful emissions that end up in our environment. The construction sector is a great contributor to the emission of greenhouse gasses, nitrogen, and particulate matter. 37% of all carbon emissions worldwide come from the construction sector as can be seen in figure 2 (UNEP, 2022). 9% of total worldwide CO2 emissions result from the production of construction materials and other construction activities and a quarter of worldwide carbon is emitted because of using and operating our built environment (UNEP, 2022). According to the European commission the construction sector is responsible for 35% of waste generation on the continent and efficient use of materials could save 80 % of this waste (European Comission, n.d.)

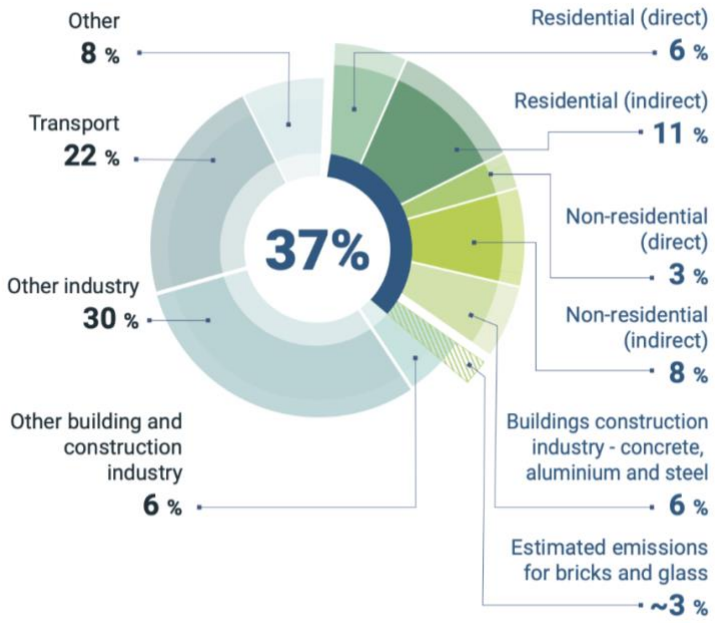


Figure 2: percentage of total global carbon emissions per sector (UNEP, 2022)

On top of the global climate crisis related to the emissions of GhG's, in the EU and especially in the Netherlands the environment is under pressure because of high concentrations of nitrogen oxides and ammoniac (Ministerie van Algemene Zaken, 2023). Nitrogen emissions in the Netherlands are mainly caused by the agricultural sector, followed by traffic, industry and consumers (RIVM, n.d.). The construction sector doesn't have a very significant impact on total Dutch Nitrogen Emissions, but it can have a negative local impact, when a construction site is located close to a protected Natura 2000 area (Ministerie van Economische Zaken Landbouw en Innovatie, 2010). Lastly, construction projects can have a negative effect on the emissions of particulate matter into the environment, which can cause health issues to humans. To limit the number of harmful substances like PM in the air, the Dutch government in collaboration with several municipalities have launched the clean air agreement (Rijkswaterstaat, n.d.).

While polluting the environment, the construction sector is fighting societal challenges like the housing shortage in the Netherlands. Therefore, its processes cannot be put to a hold. The G4 cities; Amsterdam, Rotterdam, Utrecht and The Hague aim to build 30.000 dwellings per year before 2030 (AMS, n.d.) Together with Wageningen University, Delft University of Technology, Amsterdam University of Applied Science, MIT, AMS and several market parties, these four municipalities have launched a research into the development of sustainability criteria with a focus on inner-city high-rise called 'Industrialized, modular and low-emission high-rise buildings'. (AMS, n.d.). Developing these projects within the inner city means the projects have to be of high density to meet the ambitions. For this project constructions over 30 meters are considered high-rise. Inner-city development has environmental benefits since it significantly limits the required construction of infrastructure and it will reduce car usage during operations (Bootsma, 2023)

In the Netherlands dwellings are not built by the government, which means that political ambitions like low-emission inner-city high-rise construction, must be executed by market parties. If the municipality is planning to implement new requirements in its tender documents, it is important to map the implications of low-emission high-rise construction for different parties in the construction supply chain.

Review of previous studies.

To find out what low-emission high-rise construction will mean for the business processes of market parties, previous studies on related topics are reviewed. Low-emission construction is now still an ambition rather than a reality, but there is a slow-growing interest in the field. However, compared to literature on energy-efficient buildings it is not a lot. On top of that most research is focussed on limiting the amount of carbon emissions rather than all total emissions.

Emissions from construction

As can be read in the introduction, the construction sector is responsible for a variety of emissions in several construction processes. An article by Ibn-Mohammed et al. distinguishes between two types of emissions in buildings, namely embodied emissions and operational emissions (Ibn-Mohammed et al., 2013). Operational emissions are all emissions that a building produces when it is being used, for example for heating. Embodied emissions are the emissions related to the mining of raw materials, manufacturing of constructing materials, construction logistics, construction processes on- and off-site, maintenance, renovation and at the end of a building life cycle and demolition (Ibn-Mohammed et al., 2013) Since it is a widely accepted idea that the emissions from the operational phase are higher than the embodied emissions, most academics and practitioners have focussed on that phase in research and innovations (Ibn-Mohammed et al., 2013).

When you look at Figure 3, the different life-cycle stages of a building project are separated into the product-, construction-, use- and end-of-life stage (Nwodo & Anumba, 2019). The emissions from the B stages have been analysed and solutions are widely implemented to bring down these emissions. Interesting is the recent shift in focus towards stages A, C and D instead.

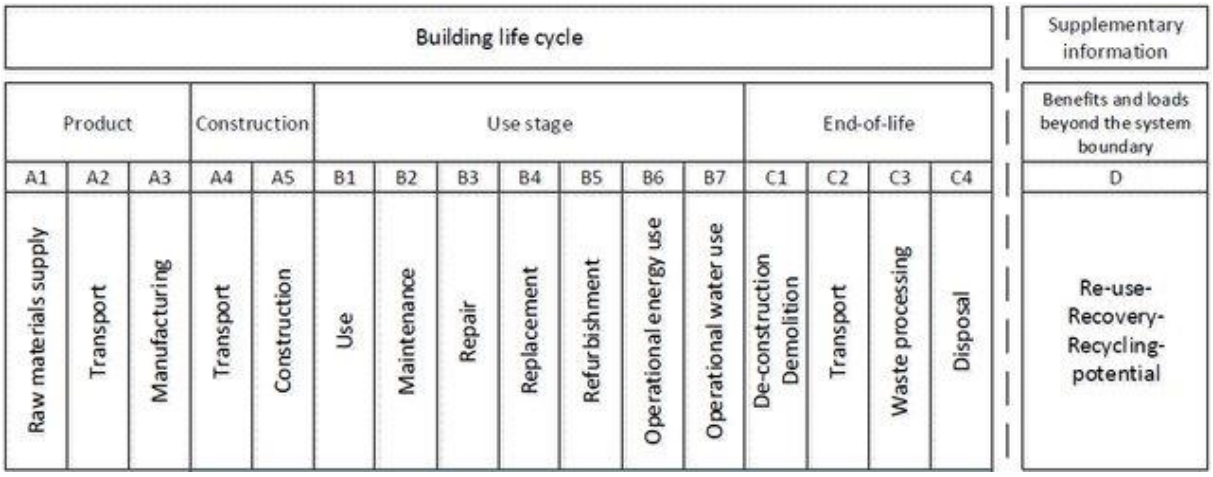


Figure 3, Building life-cycle stages (Nwodo & Anumba, 2019)

Research on what different emissions result from a construction project besides carbon and in which phase is more difficult to find. However, some calculation tools are developed to calculate these emissions for different construction types. An article by Sandanayake et al. described a method designed for contractors to determine the amount of different emissions before the construction process starts called the Construction Emission Evaluation Tool (2019). This tool considers the emissions resulting from material production, the use of equipment, transportation and the use of electricity on-site (Sandanayake et al., 2019). Another study uses a comparable Life Cycle Assessment tool like Sandanayake et al. to calculate the difference in emission between conventional and modular construction methods (Kamali et al., 2019). The boundaries of this assessment tool are comparable and multiple harmful emissions next to carbon emissions are considered in both methods and other available LCA tools in academic articles.

Some articles have used these tools to calculate differences between construction methods. In an article by Kamali et al. two modular buildings were compared to one conventional building (2019). This article concluded that not every modular building is always more efficient in terms of emissions, since one of the modular building scored below the conventional building, because many factors play a role in these calculations (Kamali et al., 2019). In another study, wooden and concrete construction techniques are compared using the same kind of tool (Sandanayake et al., 2018). It concludes that using timber instead of concrete can reduce total emissions and this tool can also assess which steps in the process have the highest impact on what emissions (Sandanayake et al., 2018).

Two studies from Sweden and Norway provide relevant insight into Low-emission construction processes and -sites. One article explores the possibilities to transition towards carbon emission-free supply chains for road production in Sweden (Karlsson et al., 2020). This article concludes that it is possible to reach an emission-free supply chain before 2045, but some impactful changes have to be made across several points in the supply chain (Karlsson et al., 2020). One of the most important takes aways from this article is that in order for the transition to take place, pathways have to be developed and coordinated on a national or international scale. Secondly, more cross-sector collaborations need to be built and maintained to benefit the transition (Karlsson et al., 2020). In a Norwegian article the possibility of moving towards emission-free construction logistics is discussed, leaving out the production of materials and energy use for equipment at the construction site (Venås et al., 2020). This

transition would require all stakeholders to engage in closer collaboration and that innovative smart public procurement could be the necessary driver in this transition (Venås et al., 2020).

As can be concluded form the studies described above, low emission construction is a broad topic with many processes and stakeholders to focus on. Only research into the emissions resulting from construction logistics, or life-cycle stages A4 and A5, concludes that stakeholder collaboration is an important driving factor (Venås et al., 2020) To find out more about the road to implementation the focus should be on a broad spectrum of possible solutions and the influence the many stakeholders have on implementing these solutions.

Green supply chain management in construction

As can be read above calculating total emissions from construction can only be done by mapping the full supply chain and other articles on Low-emission construction methods emphasize the importance of collaboration between all supply chain actors. In recent years some articles have been published on managing this supply chain and especially on Green Supply Chain Management (GSCM) or Environmental Supply Chain Management (ESCM) in construction.

GSCM developed since the 90s together with other theories linked to the environment and is essentially built around the idea that environmental considerations should play a role in supply chain management (Badi & Murtagh, 2019). This Systematic review on GSCM in construction that reviewed 204 articles showed that the unique characteristics of the construction industry and the relations between actors complicate the transition towards green practices compared to other sectors (Badi & Murtagh, 2019). Some of the literature reviewed in this article pointed towards the client/developer as an important initiator of environmental improvements. Others pointed towards designers, because of their impact on the implementation of green solutions across the design (Badi & Murtagh, 2019). In an article on the role of private parties in sustainable area development in the Netherlands Heurkens explains that developers are becoming more important in steering the sustainable transition of urban areas. Developer translate new political regulations towards visions of their own and adapt to stay competitive in new market conditions (2020). However no literature on the exact role of developers in low-emission construction can be found.

Previous literature on the topic reveals that the focus in future research should be on the entire process to prioritize the investments. Since some actors have a much higher environmental impact than others and scarce resources should be focussed to the most pollutant step in the process (Badi & Murtagh, 2019). The last recommendation from this article the request for more practical outcomes the market can work with (Badi & Murtagh, 2019). One article specifically looks into the public-private relationships in construction to see whether governmental intervention can benefit GSCM in order to reach more green practices (Xie et al., 2021). It concludes that governmental interventions can initiate resource-, knowledge- and practices sharing among industry actors and therefore benefit GSCM (Xie et al., 2021).

Another interdisciplinary review into supply-chain integration in relation to low-carbon buildings concludes that future research should focus on the relation to the end-user, like facility managers, to optimize the energy performance in use. Secondly, this article stipulates that collecting so-called ‘soft parameters’ like procurement,-contractual arrangements, team coordination and -integration should be collected throughout the sector to benefit low-carbon buildings (S. Kesidou & Sovacool, 2019).

A literature review focussed specifically on supply chain integration and low-carbon innovation in non-domestic buildings in relation to supply-chain integration (Kesidou & Sorrell, 2018) (Kesidou & Sorrell, 2018) They have analysed literature about three different topics; (construction) innovation, Supply chain integration and Low carbon buildings to develop a framework to define possible relations. Afterwards the combinations were tested in two real-life cases and in conversations with experts (Kesidou & Sorrell, 2018). According to this article, collaboration, championing, and user-involvement could improve the effect of supply chain integration on low carbon innovation. Kesidou and Sorrell explain that interdisciplinary studies in which different organizations and actors and the relationship between them could provide new insight into the topic (2018). Another gap, according to this article is the influence of behavioural and relational factors on building innovative low-carbon construction (Kesidou & Sorrell, 2018).

Research Gap

From the review of previous studies a research gap is formulated. Karlsson et al. states that for the transition towards more sustainable practices to take place changes are necessary at different points across the supply chain (Karlsson et al., 2020). In the same article the importance of collaboration within and cross-sector is pointed out (Karlsson et al. 2020). Venås et al. support this statement by seeing the value of closer collaboration in the sector (2020). In this study not only the importance of stakeholders within the construction supply chain but also the pressure from governments in the form of public procurement could be an important driver (Venås et al., 2020).

This process, however, can be complicated according to Badi & Murtagh, since the unique characteristics of this construction supply chain could be the one of the main barriers in the transition towards more green practices compared to other sectors (2019). One of the reasons for this supply chain-wide focus relates to the scarcity of resources in the sector, due to which it is extra important to focus resource use on the most impactful steps in the process (Badi & Murtagh, 2019). Kesidou & Sovacool explain that behavioural-, relational factors and 'soft-parameters' like team management, contractual agreements and procurement should be collected and shared in the sector to benefit low-carbon-buildings (Kesidou & Sovacool, 2019).

Besides the request for a supply-chain-wide view, previous studies also point out that it would be smart to focus on concrete steps towards change. Karlsson et al. for example, conclude that it would be beneficial for the pace of the transition to develop a shared pathway that can be coordinated nationally of internationally (2020). This request is supported by Badi & Murtagh, who see a lack of practical outcomes in current GSCM research in the construction industry (2019). The developer takes in an important position between political demand and market execution and can therefore play an important role in leading low-emission transition in the construction supply chain (Badi & Murtagh, 2019; Heurkens, 2020). However there is no literature that provides an answer to how the developer could organize this.

The points stated above result in the following problem statement:

The built environment puts a lot of pressure on the environment by the emission of hazardous substances. Since newly built buildings become more energy efficient a focus on emission reduction from the product-, construction-, and end-of-life stages becomes more important. Due to the unique characteristics of the construction supply chain, low-emission practices are difficult to implement. Project developers play an important role in implementing sustainable public ambitions, but it is unknown, what they can do to organize a low-emission supply chain.

Societal & scientific relevance

The societal relevance of limiting total emissions in many sectors is widely accepted by many countries and individuals over the world. The effects of global warming and the effects hazardous substances have on our environment is visible, so most governments and industries feel that changes to traditional practices and processes are becoming more urgent.

What makes this research especially relevant for society and practical for actors, is the focus on implementation of currently existing methods while considering to full supply chain. Several measures to limit emissions have been around for some time now, but they prove to be hard to implement, partly due to the complexity of the construction supply chain characteristics. With the results of this research governments and industry partners will be offered an overview of the drivers and barriers for different stakeholders on the implementation of low-emission practices along the supply chain. For the Netherlands this research is extra relevant since it touches upon multiple crises at once, the housing crisis, the nitrogen crisis, and the possibility of an upcoming carbon crisis.

Scientifically this research relates green supply chain management in construction to the implementation of emission-free construction practices in the Dutch context. Closing the gaps in scientific research on green supply chain management by considering the full supply chain and the relationships between actors. On top of that, since the configuration of the construction sector and the related regulations vary between regions and countries, a focus on the Dutch Inner-city context will possibly offer new context-specific insights into Low-emission construction of green supply chain management.

Research questions

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

How can real estate developers organize a low-emission supply chain for high-rise construction in Dutch cities?

To answer the main question, the following sub questions will be answered first:

1. How can emissions related to the construction process for high-rise construction in Dutch cities be minimized throughout the supply chain?

2. What actors internal and external to the supply-chain influence the implementation of low-emission practices for high-rise construction in Dutch cities?

3. How are low-emission practices currently implemented in Dutch high-rise construction projects and what is still missing?

4. What drives or withholds different actors to implement low-emission practices for high-rise construction in Dutch cities?

5. What role can developers take in the implementation of low-emission practices for high-rise construction supply chains in Dutch cities?

Research Output

Goals and objectives

By conducting research into the impact different actors in different steps of the construction supply chain can have on the emission of hazardous substances, a basis can be formed for new industry wide strategies. The construction sector consists out of many different actors and the composition of different actors varies from project to project, making it difficult to determine who's is to invest in which sustainable measures. The main goal of this research therefore is to offer a steering framework for developers in which they can find practices they can apply to benefit low-emission construction practices together with the other supply chain partners.

Deliverables

The main deliverable will be a steering framework that explains what steps real estate developers can take to promote the implementation of low emission practices in the construction supply chain. The research will show where barriers and drivers are within the construction supply chain of low emission projects. It is probable that new low emission construction projects ask for a different approach by the industry. The outcome of this research, however, will be hard to project on the entire industry, since it will only provide information on specific supply chains for specific projects and there will not be enough time to investigate sufficient projects to make sector-wide statements. However, for actors in Dutch inner-city projects the results will be relevant.

Dissemination and audiences

Although the focus is on the perspective of real estate developers, the output of this research can also be used by other private actors within the construction supply chain and by public parties who are looking for new policy instruments to boost Low-emission progress in the sector. Private parties can form new types of partnerships after knowing what drives other supply chain actors. Municipalities and other governmental bodies can use the information the framework will offer about their own role to improve the way they put pressure on the supply chain. The increased understanding of other roles, internal to the supply chain, can help them by creating regulation and support systems that function for the supply chain.

2 Methodology.

Chapter 2 | Research methodology

In this chapter, research methodology used to answer the before mentioned research questions will be explained. Firstly, the intended type of study will be explained. Then methods and techniques to gather necessary information will be illustrated. Lastly, the types of data collection and how these datasets will be analysed will be explained.

Type of study

In this research the goal is to provide the industry and real estate developers with strategy recommendations for low emission construction processes. The focus is to facilitate change within the sector by creating mutual understanding between industry stakeholders. To accomplish this, explorative research must be conducted, using an inductive logic of inquiry. This is an appropriate method when observations from practice need be analysed, generalized and used as input to draw conclusions that can be used sector wide. (Blaikie & Priest, 2019)

This thesis uses a systems approach to develop a low-emission construction strategy that is based on both theoretical and practical findings and integrates the key construction supply chain actors. Primarily qualitative information is important to be able to find a complete answer to the research questions. The qualitative data will be collected about factors influencing behaviour within the supply system and within individual organizations.

Methods and instruments to be used

To get a better understanding of what steps in the construction supply chain should be approached differently in the future, it is important to map business as usual first. Therefore, literature research on construction supply chain management, green supply chain management and Low-emission construction will be performed to provide this thesis with the current body of knowledge on the structure of construction supply chains and low-emission construction practices. After the theoretical part, empirical research is needed to confirm theoretical findings and modify the, identify case and context specific characteristics, and identify practical implications. The sub questions, objectives and brief description of methods and instruments are described below. A visualisation of the research process can be seen in figure 4.

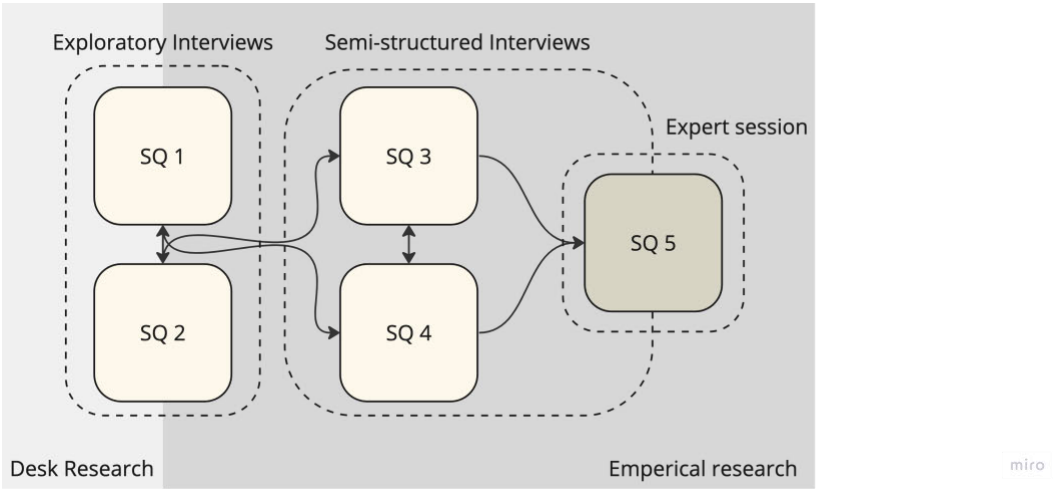


Figure 4, Research design and interconnections between sub questions (own illustration)

Sub question 1: How can emissions related to the construction process for high-rise construction in Dutch cities be minimized throughout the supply chain?

Objective: Explore measures that can be taken by supply-chain actors to limit construction related activities from inner-city high-rise projects and link them to certain steps in the construction supply chain and Green Supply Chain Practices.

Methods & instruments: The literature in the theoretical background will form an important basis for determining the themes and practices. This information will be tested by exploratory interviews with industry stakeholders.

Sub question 2: What steps and actors internal and external to the supply-chain influence the implementation of low-emission methods for high-rise construction in Dutch cities?

Objective: Explore the most important stakeholders in low emission project and determine their role in implementing the low emission practices identified in sub question 1.

Methods & instruments: Empirical research through exploratory semi-structured interviews with different types of stakeholders in the construction supply chain.

Sub question 3: What drives or withholds different actors to implement low-emission methods for high-rise construction in Dutch cities?

Objective: Explore the stakeholder specific barriers and drivers for implementing low-emission methods for high-rise construction and the relationships between the barriers and drivers different actors experience.

Methods & instruments: Empirical research through semi-structured interviews with key stakeholders in the case study projects.

Sub question 4: How are low-emission practices currently implemented in Dutch high-rise construction projects and what is still missing?

Objective: The goal here is to identify these practices that several stakeholders acknowledge, but are not yet put to practice enough yet, because of existing barriers.

Methods & instruments: Empirical research through semi-structured interviews with key stakeholders in the case study projects.

Sub question 5: What role can developers take in the implementation of low-emission practices for high-rise construction supply chains in Dutch cities?

Objective: Identify what the necessary methods and practices are that a real estate developer should apply in order to stimulate low-emission methods and practices across the supply chain, either by directly executing them or by directly or indirectly influencing other stakeholders.

Methods & instruments: Empirical research through semi-structured interviews with key stakeholders in the case study projects. After the first conclusions can be drawn from the semi-structured interviews a validation session with several experts from the industry will be organized to discuss the results.

Data collection

The collection of qualitative data will be done through interviewing the involved stakeholders and will show the barriers and drivers for the use of sustainable construction methods from the perspective of different stakeholders in the same project. When certain conclusions can be drawn from the qualitative data from the stakeholder interviews, focus group sessions with the project supply chains can be organized to reflect on the process and collectively draw lessons for future supply-chain wide strategies.

In this research multiple real-life cases will be used that comply with the selection requirements. Since this research is part of a bigger research that focusses on both limiting total emissions and speeding op de pace of construction, projects used for this thesis should preferably share these ambitions. The reason multiple cases are selected for this thesis is to improve the chances of performing a successful one. Analysing data from two or more case studies is beneficial compared to one case study (Yin, 2018).

The reason to select case studies as most suitable research method, is because case studies can provide a detailed description of an event or process (Yin, 2018) Information of real-life events is useful for this research, since it is meant to provide guidance for practitioners. The exact boundaries of the events or processes are not determined upfront and can further be determined during the process.

This graduation thesis will take place in collaboration with project developer Synchroon as graduation company. Synchroon is a private commercial real estate developer and is part of TBI Group. Synchroon is one of few real estate developers in the Netherlands who have published their own view on a Low-emission construction. Synchroon already aims to not only limit their own emissions, but also the emissions of supply-chain partners, which makes them an interesting partner in the research. The developer can help in finding suitable research cases and get in touch with experts in the field.

Data analysis

Qualitative data collection in the form semi-structured interviews with the involved stakeholders will show the barriers and drivers for the use of sustainable construction methods from the perspective of different stakeholders in the same project. The qualitative data will be collected through semi-structured interviews in which the topics are determined beforehand but the exact structure of the interview leaves room for unexpected input. The interviews will be transcribed and coded based on the

main concepts in this thesis research. The analysis of the interviews will be done through ATLAS.ti. The cases or project organizations will for the units of analysis in this research.

Data Management Plan

To be able to adhere to the a data management plan was created that complies to the FAIR principles for scientific data. This means data used in this thesis should by Findable, Accessible, Interoperable and Reusable (*FAIR Principles*, n.d.). The data Management plan was created using the TU Delft platform of DMPonline to assure all measures are taken to safely store and collect it. The Complete Data Management Plan together with the Human Research Ethics Committee application and the informed consent form can be found in the appendix.

Ethical Considerations

This research will use data collected through interviews which means people will be involved in the research and they have to be protected against negative consequences that could possibly result from their involvement to this research. No sensitive personal data will be collected. Only their role within the project and their organization is important to this research. Information about the organizations involved could be sensitive, since it could reveal their way of working to other organizations in the sectors, which means they could lose their competitive advantage. This is something that has to be taken seriously and the type of data to be collected and shared need to be motivated and agreed upon in collaboration with these organizations.

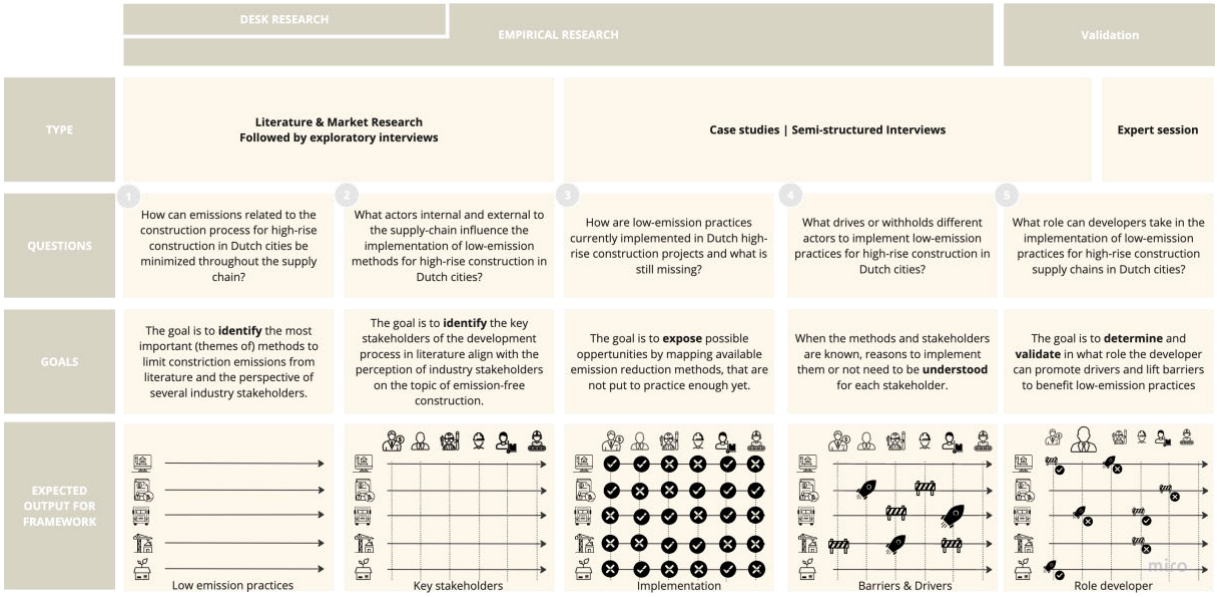


Figure 5, research methodology (own work)

3 Theoretical background.

Chapter 3 | Theoretical Background

Unique Supply chain of the construction Industry

When focusing on the possible reconfiguration of the construction-supply-chain to benefit Low-emission construction it is important to map the construction supply chain and the industry characteristics. Some of these characteristics make it difficult for the supply chain to be organized like in other industries. Vrijhoef and Koskela discuss the unique characteristics or peculiarities in their in an attempt to find out whether these can possibly be cancelled out (2005). In figure 6 below the three most important peculiarities on a production scale are shown and relationships between these factors are descried.

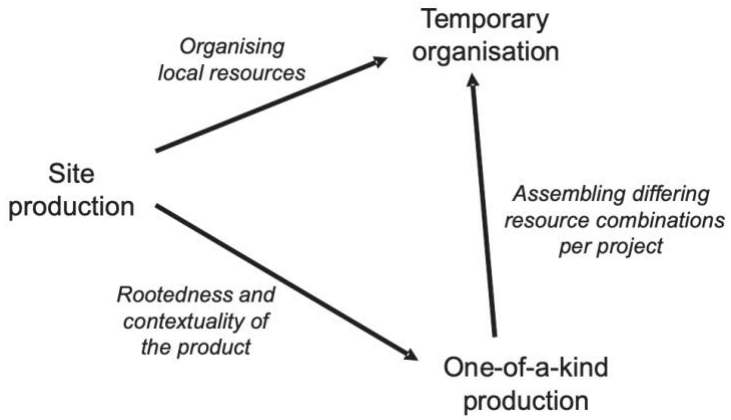


Figure 6, Relations between project/production particularities (Vrijhoef & Koskela, 2005)

Site production in construction can of course be limited by choosing for off-site production methods, but the final product will always be designed in relation to the soil conditions and other physical factors that are specific to the site (Vrijhoef & Koskela, 2005) This relates closely to the one-of-a-kind character of construction projects, since site characteristics play an important role, but also other contextual factors like for example economics and institutions can play an important role (Vrijhoef & Koskela, 2005) This one-off approach doesn't by definition have to be a negative peculiarity, since increasing repetitiveness would perhaps negatively influence design and the creating of value (Ballard, 2005).

The last peculiarity is cause by the other two, since the request of one-off-a-kind products on specific locations logically leads to a unique and possibly local assembly of resources, a temporary organization (Vrijhoef & Koskela, 2005). Vrijhoef and the Ridder have created the model in figure 7, which divides the construction of a building in a demand and a supply system (Vrijhoef & Ridder, 2005). In this process of delivering these one-off projects a lot of different types of stakeholders are involved on both the demand and the supply side.

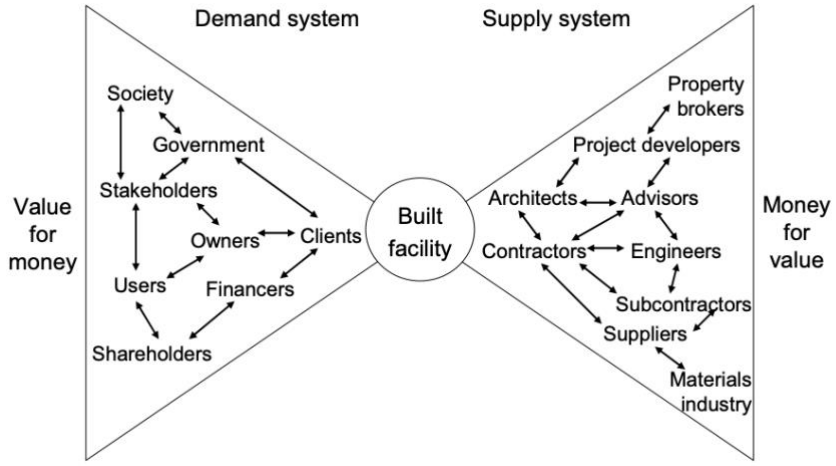


Figure 7, Value demand and supply system in construction (Vrijhoef & de Ridder, 2005)

Compared to other sectors, the demand side of this system has a relatively big influence on the process, since it is are mainly the client and the government who will formulate the requirements and regulations the product needs to adhere to (Vrijhoef & de Ridder, 2005). On the supply side actors are differ in type, size and configuration, while on the demand side, the actors are quite well organized. According to Vrijhoef and the Ridder this makes the construction sector 'pull' driven compared to industries like manufacturing, where actors on the supply side are well organized and 'push the product over to the demand side (2005).

Since focusing on all of actors in figure 7, would be difficult to manage for this master thesis, only the most important demand and supply system stakeholders will be further investigated.
In chapter 4 of his book managing construction projects, Winch explains the roles of different construction project stakeholders and what their involvement in the project is. As can be seen in figure 8 he has divided stakeholder into internal and external stakeholders (Winch, 2010).

Internal stakeholders		External stakeholders	
Demand side	*Supply side*	*Private*	*Public*
Client	Architects	Local residents	Regulatory agencies
Financiers	Engineers	Local landowners	Local government
Client's employees	Principal contractors	Environmentalists	National
Client's customers	Trade contractors	Conservationists	Government
Client's tenants	Materials suppliers	Archaeologists	
Client's suppliers		Non-governmental organisations (NGO)	

Figure 8 List of stakeholders in a construction project (Winch, 2010)

The internal stakeholders are divided into a demand- and supply side, just like in figure 7. For this research, only the internal supply chain side actors and actors that have direct influence on this supply chain, from 'pulling' or regulating it, will be considered.

In the Netherlands the most important governmental body in construction projects is the municipality, since they are responsible for setting up the land-use plan and for granting construction permits to new projects (Hobma & de Jong, 2016). Together with the Client and the Financiers, the municipality will form the group of most important stakeholders on the demand side of construction projects, just like in figure 7 by de Ridder and Vrijhoef (2005). In the case of inner-city (residential) high-rise development in the Netherlands, the client will often be a real estate developer. The Architect, principal contractor, trade contractor and supplier will together form the group of most important supply side actors. The engineer is left out in this thesis, since they will be consulted by both the contractor and the architect for building projects and therefore their input will probably arise from conversations with these parties.

In a traditional construction projects the stream of information doesn't follow the stream of materials as can be seen in figure 9 below. The figure shows that the relation between the demand and supply side within a construction project is not as linear as figure 7 would suggest. Traditional construction projects are make-to-order, which means that the building delivered is delivered unique and according to the requirement set up by the demand side (Vrijhoef & Koskela, 2000).

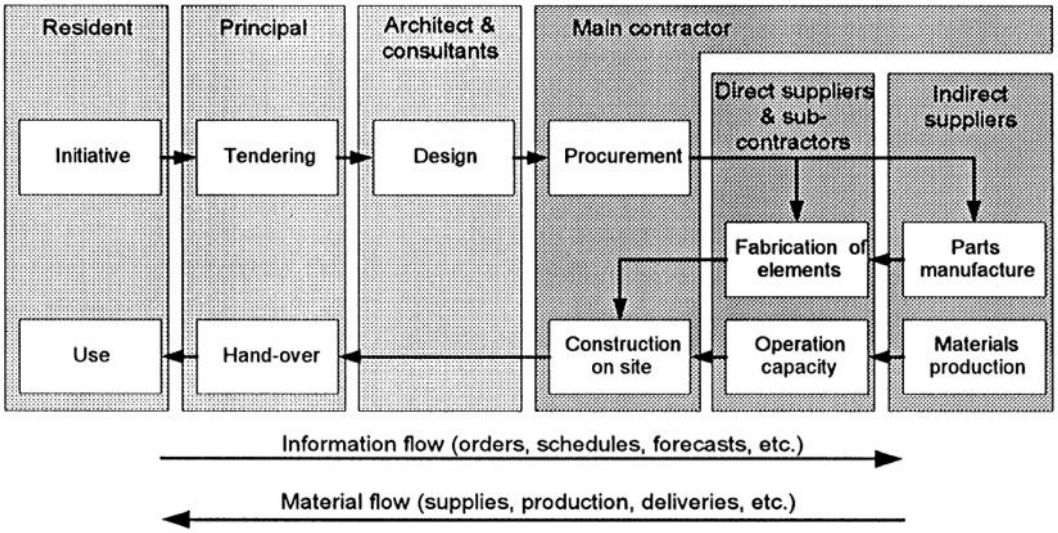


Figure 9, Typical configuration of a traditional construction supply chain

A more integrated construction supply chain could be beneficial for the implementation of Low-emission construction techniques, since investments in time and money ask for an orchestrated approach from the industry and Vrijhoef and de Ridder explain that supply chain integration could improve efficiency and effectiveness (2005). Aligning a construction supply-chain is a complicated task, which conflicts with the very elementary characteristics of the construction industry described at the beginning of this paragraph (Vrijhoef & de Ridder, 2005). According to this article the integration of the two sides of this system which each other and with the other side, asks for a stakeholder or organization on both sides of the system responsible for integration; the supply system integrator and the demand system integrator (Vrijhoef & de Ridder, 2005).

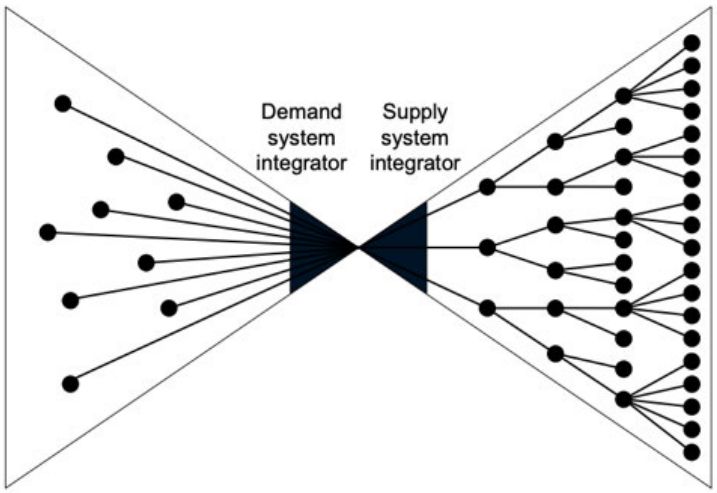


Figure 10, The central role of the demand and supply system integrator (Vrijhoef, 2011)

In figure 10 an illustration of the two system integrators within the bigger supply and demand system is illustrated. The role of demand system integrator is traditionally filled by client organizations (Vrijhoef, 2011). A client organization can be a future owner or a developer. When a client organization who adjust their procurement strategies effectively can align the supply system as well, which puts them in the position of system integrator (Vrijhoef, 2011). While this is a possibility and organizations on the supply side need initiation from the demand side, supply side actors take on the role of supply side integrator independently. This would usually be a contractor, but architects and developer can take such a position as well (Vrijhoef, 2011). A further description of the role of the project developer as supply chain integrator is discussed in the paragraph on stakeholders on page 37.

Green Supply Chain Management

In literature multiple sustainable perspectives on supply chain management have arrised. Green Supply Chain Management, Environmental Supply Chain Management and Sustainable Supply Chain Management are all integrations of environmental reflection into the supply chain. In green supply chain management, the main focus is on the integration of environmental concerns into this chain to, in the end, reduce the negative impact the production process will have on the environment (Badi & Murtagh, 2019) These environmental concerns touch upon more topics than just the emissions embodied in the construction process of the main load bearing structure and the facade, but lessons could possibly be transferable. Therefore Green supply chain management theory will be used as a starting point for developing Zero-Emission Supply Chain theory.

A characteristic of GSCM in construction is that some principles of GSCM conflict with that of the construction sector. One of them is the focus on long lasting relationships for example. The construction industry is organized into projects with temporary partnerships, while sustainable relationships that are built on trust prove to be beneficial for greening supply chains. (Badi & Murtagh, 2019) The article also questions whether lessons about green supply chain management can be transferred between subdomains like domestic or non-domestic developments (Badi & Murtagh, 2019).

Balasubramanian & Shukula from Middlesex University have performed a literature research into green supply chain management in order to develop an assessment framework for GSCM in different stages

of the construction project (2017a) Their final product is a nine-construct model that include internal and external barriers and drivers in relation to core and facilitating green practices and organizational, economic and environmental performance (Balasubramanian & Shukla, 2017a).

For all constructs in their framework, the relevance of it to each of the four stakeholders, being the developer, the architect, the contractor, and the supplier is indicated in their article (Balasubramanian & Shukla, 2017a). The municipality is incorporated in the framework, but not as an internal stakeholder, but as an external driver, putting pressure on green development using green related regulations (Balasubramanian & Shukla, 2017a). The core green practices of their framework cover the entire construction supply chain excluding the occupancy phase.

The five core practices are green design, green purchasing, green transportation, green construction and -manufacturing and green end-of-life management (Balasubramanian & Shukla, 2017a). These five core practices closely relate to the minimum of six activities that an organization should focus on in pursuit of net zero harming the environment described in the literature review by (Badi & Murtagh, 2019). These six activities are; green purchasing, green design, green manufacturing, green logistics, waste management, green operation and end-of-life management (Badi & Murtagh, 2019). However, in the framework by Balasubramanian and Shukla waste management and end-of-life management is subject to Green construction and Manufacturing and green operations are part of the green design (Balasubramanian & Shukla, 2017a) What do these concepts entail and what internal barriers and drivers influence the implementation of green practices in the construction supply chain?

Green Design

In a research paper by Zhang et al the implementation of green strategies across the different phases of housing development in China and the barriers, drivers and competitive advantages that result from it are reviewed (2011). For the design phase the key green elements stakeholders could focus on are focussed on location selection, orientation and design choices that lead to an energy efficient building and no impact of the design phase on the selection of sustainable materials is discussed (Zhang et al., 2011).
NG et al. do acknowledge the effect of the planning and design phase on the emissions later in the process. They explain that knowledge about the emission impact design choices have in later phases, can help designers in recognizing emission reduction potential of different choices (Ng et al., 2012). A green construction activity in the design phase is the replacement of materials with a high embodied energy, such as concrete-steel structures, by more environmentally friendly materials (Ng et al., 2012).

Green Purchasing

According to the literature review by Balasubramanian & Shukla, green purchasing can be divided into the procurement of materials and the tendering process (2017a). Certain criteria's need to be present in these stages to implement green supply chain management in the procurement process (Balasubramanian & Shukla, 2017a). Since 'purchasing' is more transactional and 'procurement' covers the strategic process of getting to those transactions in a more suitable way, in this thesis green procurement will be discussed from this point on.

In an article about sustainable supply chain management in construction not only environmental but also social and economic considerations in the construction process are discussed (Adetunji et al., 2008).

In this article they discuss the importance of sustainable procurement and mention procurement as a tool to influence the avoidance of the use of hazardous materials and the use of certain vehicles for example. At the same time laxity in procurement and the focus on price is seen as one of the main barriers of the implementation of sustainability in supply chain management (Adetunji et al., 2008).

In a study by Shen et al. the most important factors influencing green procurement in building construction are investigated through literature research and a questionnaire (2017). The most important reasons to implement green procurement are policy pressure, marketing benefits and business benefits for the organization. The most influential factors however, are market benefits, market pressure and internal pressure (Shen et al., 2017). In this case the focus was on the procurement behaviour of the real estate developer and it turned out that this behaviour was influenced mostly by external factors, like customers and competitors (Shen et al., 2017).

Green Logistics

In an article on the reduction of carbon emissions during the life cycle of a project, logistics is seen as an important contributor to the emissions during the construction process (Ng et al., 2012). Not only the distance, but also the type of transportation must be considered to minimize emissions. Using local materials could have a significant impact on the carbon emissions as well (Ng et al., 2012). Green logistics, according to a literature review by Setyaning et al., concerns the movement of goods as the movement of people to ad from construction sites (2020). Employees can be encouraged to work from home or in case of workers, use shared mobility to travel to the construction site (Setyaning et al., 2020). However, as will be discussed in the next paragraph about construction emissions, material transportation contributes for a great part to the total emission during construction. Therefore, transporting materials in fuel efficient vehicles and in full truckload are important green activities for the construction industry (Setyaning et al., 2020).

Another important article on construction emissions and the influence important actors can have is from Fredriksson & Huge-Brodin (2022). Here low-emission logistics is seen as a concept with multiple scale levels and three important groups of actors; developer, contractor sand municipalities (2022). According to this article responsibility for clean construction logistics should be with the municipality, since decisions on land-use restrict what plans can be made by developers and plans of developers restrict the logistics by contracting parties. Clients should therefore demand a change in modal split and energy efficiency of their contractors based on land agreements with the municipality (Fredriksson & Huge-Brodin, 2022).

Green Construction and manufacturing

In the same article by Zhang et al. (2011) elements of green construction do cover the use of environmentally friendly materials, waste management and the use of pre-fabrication, which are measures discussed in the paragraph on zero-emission construction techniques. Major barriers result from the unfamiliarity of actors with these methods that come with delays during approval and construction processes, technical difficulties during construction and risks related to different project delivery forms (Zhang et al., 2011). Not only on the construction site, but also before, during the manufacturing process, it is important to pay attention to possible negative effects of processes on the environment.

Low-emission construction

Emissions in Construction

Green Supply Chain Management is not directly the same as managing a Low-emission construction project. In the process of producing a Low-emission Construction Supply Chain Blueprint, the GSCM practices applicable to Low-emission construction need to be defined. Most studies consider a few important substances when assessing the impact of the construction process. A study into the use of resources and Emissions for the U.S. construction sector focuses on CO, SO2, NO2, Particulate Matter, CO2, Hazardous waste, toxic releases into the air, volatile organic compounds, and the five largest toxic air emissions; Hydrochloric acid, Chlorine, Ammonia, Methanol & Toluene (Hendrickson & Horvath, 2000). In this paper the first five abovementioned substances are the largest contributors. In another study that focuses on creating an emission calculation and decision-making tool only considers CO, SO2, NO2 Particular Matter and CO2 and HC (Sandanayake et al., 2019). The clean and emission-free construction program of the Dutch national government only focuses on Nitrogen emissions (NO2) Carbon emissions (CO2) and particulate matter (Ministerie van Landbouw Natuur en Voedselkwaliteit, 2021). Measures that limit these three types of emissions will also be the focus of this thesis.

Choosing a specific material or a construction method can have environmental effects in multiple phases. In an article by Sizirici, carbon emissions in different stages of a construction process and possible methods to reduce emissions in these stages are described with a special focus on manufacturing, logistics, construction, operation and maintenance, and end-of-life deconstruction (2021) This study concludes for their specific case that mining and manufacturing accounts for up to 90% of the total carbon emissions (Sizirici et al., 2021). Therefore, selecting sustainable materials is very important. Next to mining and manufacturing of materials, transport of materials and on-site construction processes are also considered.

Knowing at which stage air emissions are emitted and by what type of activity is essential to investigate possibilities to mitigate these harmful emissions. An inventory analysis and a case study by Zhang et al. (Zhang et al., 2013) reviews the emission of several important air pollutants in six phases of the project life cycle. The air pollutants that are used in this research are carbon dioxide, methane, nitrous oxide, sulphur dioxide, carbon monoxide, nitrogen oxide, non-methane volatile organic compounds and particulate matter (Zhang et al., 2013). According to this paper air emissions during the material manufacturing phase are caused by using vehicles that on fossil fuels and by using electric equipment. Different materials have their own emission factor which is multiplied by the amount in Kg of the material to determine the emissions (Zhang et al., 2013). Table 1 shows what the factor of each material is on different emissions.

Emission factors from the seven major building materials at manufacture stage (g/kg).

Material	Emission factors							
	CO_2[a]	CH_4	N_2O	SO_2	CO	NO_X	NMVOC	PM
Concrete	106[a]	ND	ND	0.0039[b]	0.0081[b]	0.0045[b]	0.0042[b]	0.0016[b]
Cement	994[a]	0.0273[c]	0.0273[c]	1.3217[c]	0.6281[c]	2.4413[c]	0.0273[c]	0.6[d]
Steel	1242[a]	1.3714[c]	0.0259[c]	5.2009[c]	92.8913[c]	2.7428[c]	1.8113[c]	2.03[d]
Aluminium	8000[a]	ND[c]	ND[c]	54.4[c]	441.6[c]	6.4[c]	1.6[c]	49[d]
Glass	1735[a]	ND[c]	ND[c]	10.8719[c]	0.4626[c]	16.6549[c]	0.2313[c]	0.4[d]
Sand	6.9[a]	ND	ND	0.00014[e]	0.0189[e]	0.016 [f]	0.00124[e]	1.1453[f]
Timber	−1665[a]	0.00065[g]	ND	0.01[g]	0.8[g]	0.55[g]	0.475[g]	0.35[g]

Note: ND means no data.

Table 1, emission factors from the seven major building materials at manufacture stage (Zhang et al., 2013)

It becomes clear that when it comes to carbon dioxide emissions, timber has the lowest impact and aluminium has a very high impact. So if the only criteria would be to lower production-related carbon emissions, timber would be a very good decision.

The next phase in which air emissions are emitted is the logistics phase. The emissions in this phase can be calculated by multiplying the weight of the materials in tons with the distance and the emission factor of the selected transport mode (Zhang et al., 2013). In this research, the only modes of transport are deep-sea transport, coastal vessel, road freight and railroad and no electric modes of transport have been used in the calculations (Zhang et al., 2013).

Thirdly, during the construction phase of a building, air emissions result from the use of equipment and vehicles and the transportation of waste. The first category can be calculated by multiplying the amount of energy used by the emission factor of either diesel or electricity. The second category can be calculated by multiplying the tons of waste times the distance to the landfill site and the mode of transport (Zhang et al., 2013).

Minimizing construction emissions

Bio-based, Industrialized, Modular, Zero-emission and Circular construction, or BIMZEC construction is a novel concept. It is a translation of the main focus points in the nitrogen approach by this research group (AMS, n.d.). In this approach the focus in on the use of lighter and more sustainable construction materials, which is translated to bio-based materials in this thesis. Secondly, producing and manufacturing off-site can benefit the efficiency and environmental impact of manufacturing. Therefore Industrialization, modular- and circular construction are also added to the requirements. Lastly, the emissions resulting from vehicles and equipment should be decreased to reduce the emissions of the entire process. These elements can be part of the zero-emission process and will therefore be explained further.

Bio-based construction

One study involved multiple actors from the Swedish construction industry in their research and discussed several statements related to a transition towards wooden multistorey construction practices in 2030 with them (Toppinen et al., 2018). In this article they investigate three elements that should benefit the greening of the construction supply chain. These are the Value configuration, Necessary competencies or capabilities and the necessary partner network for this new business model (Toppinen et al., 2018).

All respondents agree on the fact that co-operation in the wood-construction business should increase over the years. Most companies also expressed their wish for new players on the market and increased quality (Toppinen et al., 2018). None of the respondents mentioned the end-user as an important actor is the future network, which leaves room for possibilities according to Toppin et al. (2018). One conclusion relates to the project-based relationships between actors. Service dominant logic could allow companies services designed from a sustainability viewpoint (Toppinen et al., 2018).

Industrialized- and modular Construction

Industrialization and modular construction are strongly related to each other since off-site fabrication of modular construction elements is often associated with an industrialization of the process. What modular prefabrication means for the construction process in terms of sustainability was reviewed by Jiang et al. based on sixteen indicators of which six concern environmental sustainability and the other ten concern social-, and economic sustainability (2019) The results show that prefabrication has a significant positive effect on the environmental sustainability. Prefabrication can save more than half of steel and concrete use and 76% of on-site formwork (Jiang et al., 2019). Since mining and manufacturing of materials contribute for 90% of total construction-related emissions, saving materials can have an important impact (Sizirici et al., 2021).

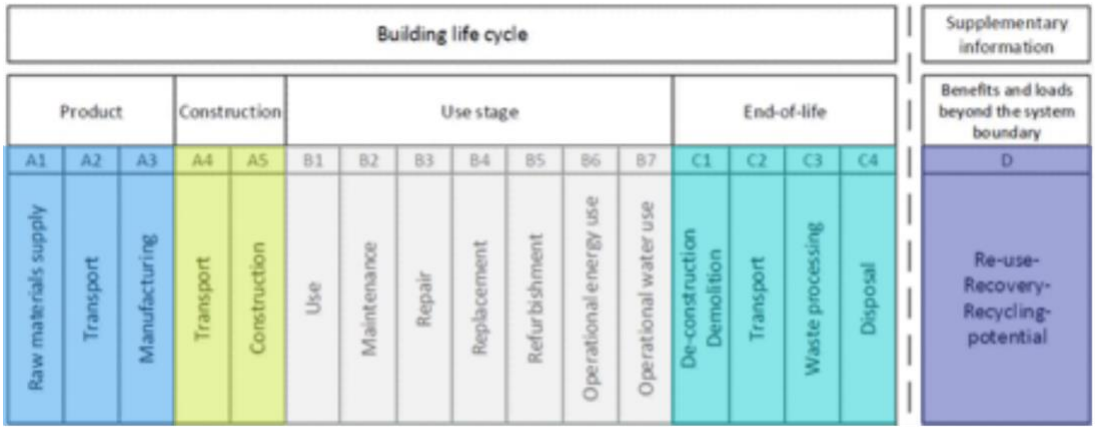
In another article, a framework was presented to assess the differences between conventional and modular construction, which focusses on the impact on the environment, time, and costs (Hammad & Akbarnezhad, 2017). When testing the framework on a modular and a conventional project, the modular projects both the embodied carbon, costs and duration of the modular case study were significantly beneath that of the conventional case (Hammad & Akbarnezhad, 2017).

Circular Construction

One article did research into the implementation of the circular economy in the building sector (Leising et al., 2018). Circular economy pilots are reviewed, and this theory is used to study the collaboration within the construction supply chain to learn about the relationships, visons, actor learning, dynamics and business model innovation. Finally, a collaboration tool is created using the empirical findings from three real life cases in the Netherlands (Leising et al., 2018) The tool is divided 5 different phases in the building sector and is written from the perspective of the focal party of that phase (Leising et al., 2018).

According to the article the client should be the one taking the initiative to not only set up requirements but also envision a collaborative process together with other supply chain actors (Leising et al., 2018). In the second phase multidisciplinary teams have to be formed who work together DBM contracts. Shared goals and trust are more important than detailed descriptions during this and the next stage of the process. This collaboration also needs to be supported technically by BIM software (Leising et al., 2018) The construction phase is the moment in which the investments are made, which relates to everyone's business models. According to Leising et al. business model should move from the current situation, where every actor focusses on receiving the highest margins, to a collective financial aim between actors (2018).

As previously discussed Green Supply Chain management in construction consists of several core practices (Balasubramanian & Shukla, 2017a).However, not all GSCM practices are relevant for the reduction of construction emissions. Therefore those practices that are relevant for this thesis have been filtered out of the list based on the impact these practices would have on phases A1-5, C1-4 and D of the building life cycle stages. Table 2, shows the different low-emission practices and on which life cycle stage the practices will have an impact. The new table of core practices for low-emission construction processes can be seen in table 3 below.



Constructs and items	Stakeholder relevance D	AC	C	S	Literature source (Construction and other sectors)
Core green practices					
Green design					
Environmental impact assessment of design (GRDSGN1)	✓	✓			Ng *et al.* (2012), Zhang *et al.* (2011)
Provision for natural ventilation (GRDSGN2)	✓	✓			Ng *et al.* (2012), Zhang *et al.* (2011), Liu *et al.* (2012)
Provision for natural lighting (GRDSGN3)	✓	✓			Ng *et al.* (2012), Zhang *et al.* (2011), Liu *et al.* (2012)
Provision for waste water recycling (GRDSGN4)	✓	✓			Zhang *et al.* (2011), Lui *et al.* (2012)
Integration of photovoltaic panels (GRDSGN5)	✓	✓			Ng *et al.* (2012), Zhang *et al.* (2011)
Consideration for energy efficient lighting system (GRDSGN6)	✓	✓			Ng *et al.* (2012), Zhang *et al.* (2011)
Consideration for energy efficient heating and air conditioning (HVAC) systems (GRDSGN7)	✓	✓			Ng *et al.* (2012), Zhang *et al.* (2011)
Provision for the use of prefabricated components (GRDSGN8)	✓	✓			Ng *et al.* (2012), Zhang *et al.* (2011)
Consideration of materials with high recycled content and low embodied energy (GRDSGN9)	✓	✓		✓	Liu *et al.* (2012), Zhang *et al.* (2011), Ng *et al.* (2012)
Consideration to reduce the use of hazardous materials (GRDSGN10)	✓	✓		✓	Liu *et al.* (2012), Zhang *et al.* (2011)
Green purchasing					
Environmental criteria(s) are included in material purchase decisions (GRPURC1)	✓		✓	✓	Ofori (2000), Adetunji *et al.* (2008)
Environmental criteria(s) are included in tendering (GRPURC2)	✓		✓	✓	Varnas *et al.* (2009), Adetunji *et al.* (2008)
Green transportation					
Provision of accommodation to employees near project sites (GRTRAN1)	✓	✓	✓		BRE (2003)
Use of video conferencing (GRTRAN2)	✓	✓	✓	✓	TemaNord (2010)
Employees are encouraged to use shared transport and public transport (GRTRAN3)	✓	✓	✓	✓	BRE (2003)
Materials are transported in full truckload quantities (GRTRAN4)			✓	✓	BRE (2003), Ng *et al.* (2012)
Materials are transported in fuel efficient vehicles (GRTRAN5)			✓	✓	BRE (2003), Ng *et al.* (2012)
Green construction/green manufacturing					
Provision for waste water recycling at project/manufacturing site (GRNCON1)/(GRNMAN1[a])			✓	✓	Zhang *et al.* (2011), Shrestha (2016)
Use of prefabricated components in projects (GRNCON2)			✓		Jaillon *et al.* (2009), Zhang *et al.* (2011)
Use of materials with high recycled content and low embodied energy (GRNCON3)			✓		Shrestha (2016)
Reducing use of hazardous materials (GRNCON4)			✓		Shrestha (2016)
Comprehensive waste management plan for project/manufacturing sites (GRNCON5)/ GRNMAN2[a])			✓	✓	Shen and Tam (2002), Zhang *et al.* (2011)
Automation is used for onsite construction/manufacturing activities (GRNCON6) GRNMAN3[a])			✓	✓	Jaillon *et al.* (2009), Chen *et al.* (2010)
Fuel efficient equipment/machinery are used at project/manufacturing site (GRNCON7) GRNMAN4[a])			✓	✓	Shen and Tam (2002), Shi *et al.* (2013)
End-of-life management					
Environmental impact assessment during end-of-life demolition of projects (ENDMGT1)			✓		Ofori (2000), Ng *et al.* (2012)
Material from the end of life demolished projects is recycled (ENDMGT2)			✓		Ofori (2000), Ng *et al.* (2012)

(continued)

Table 2, Low-emission practices filtered from GSCM Practices filtered for relevant life-cycle stages (Balasubramanian & Shukla, 2017a)

Core low emission construction practices
Green design
Environmental impact assessment of design
Provision for the use of prefabricated components
Consideration of materials with high recycled content and low embodied energy
Consideration to reduce the use of hazardous materials
Green procurement
Environmental criteria(s) are included in material purchase decisions
Environmental criteria(s) are included in tendering
Green logistics
Provision of accommodation to employees near project sites
Use of video conferencing
Employees are encouraged to use shared transport and public transport
Materials are transported in full truckload quantities
Materials are transported in fuel efficient vehicles
Green construction/green manufacturing
Use of prefabricated components in projects
Use of materials with high recycled content and low embodied energy
Reducing use of hazardous materials
Comprehensive waste management plan for project/manufacturing sites
Automation is used for onsite construction/manufacturing activities
Fuel efficient equipment/machinery are used at project/manufacturing site
End-of-life management
Environmental impact assessment during end-of-life demolition of projects
Material from the end-of-life demolished projects is recycled

Table 3, low emission construction practices (own table based on Balasubramanian & Shukla, 2017a)

Barriers and drivers in a low-emission construction process

Literature on the barriers and drivers in low-emission construction processes is scarce. There is research into barriers and drivers in related topics, such as the adoption of green supply chain management or circular economy principles. Based on these sources an idea on the barriers and drivers in low-emission supply chains can be created.

Balasubramanian & Shukla separate external barriers and internal barriers to stakeholders. Externally stakeholders can experience a lack of collaboration between the project stakeholders. Also, a shortage of both green materials and green professionals can limit the implementation. Lastly, the inflexibility in deadline set by the developer is experienced as a barrier by the architect, consultant, and contractors (2017b). Internally the high costs related to green design and construction and insufficient knowledge and awareness of green practices can be a barrier (2017a)

In a literature review on the global implementation of green building principles, five barriers were mentioned in many of the studies. In 35 of the 36 studies, the lack of information, research and

knowledge at stakeholder organizations is mentioned as important barrier. The second most mentioned barrier is literature is cost and that this is experienced by all stakeholders that have a strong focus on cost in projects. Also lack of incentives from governments, interest and demand from stakeholders, and regulations to enforce green building are mentioned as important barriers (Darko & Chan, 2017).

Another literature review on the barriers and drivers that are experienced by different construction stakeholder doesn't discuss the implementation of green supply chain management, but the perspective towards the circular economy (Munaro & Tavares, 2023) The goal of this study is to review the most important barriers, drivers and stakeholders in the transition towards the efficient use of resources to limit environmental impact, which is in line with the motivation behind green supply chain management (Munaro & Tavares, 2023) This study doesn't classify barriers and drivers as internal and external but defined five categories; Economic, Informational, Institutional, Political and Technological. The categories and an explanation can be seen in table 4.

Category	Topics
Economic	Economic-/ financial market, (lack of) financial aid and subsidies, costs.
Informational	(Lack of) knowledge, research, education in society.
Institutional/Organizational	(Lack of) knowledge, integration, awareness and information for stakeholders.
Political	(lack of) government policies regulations, fiscal actions, or a governance plan.
Technological	(Lack of) the development of technologies, infrastructure and tools.

Table 4, Five barrier and driver categories and their explanation (own work based on (Munaro & Tavares, 2023)

The most important barriers according to this article are, consecutively, Politcical lack of regulation and vision, technological lack of a suitable information system integrated processes and tools, economic like lack of financial support and lastly institutional and informational barriers (Munaro & Tavares, 2023).

External drivers for the implementation of green practices are regulations by the government, which mainly effects developers and contractors in the supply chain, and pressure from supply chain actors and competition (Balasubramanian & Shukla, 2017a). Internally a commitment to improve environmental performance and improve the organizations reputation (Balasubramanian & Shukla, 2017a).

When looking at the categories in table 4 the most important category of drivers are political, financial support and fiscal actions and regulations. These are followed by technological drivers that mostly focus on digital information systems and correct guidelines and tools. On the third place are institutional drivers and the in the form of strategic visions (Munaro & Tavares, 2023). That political drivers are seen as the most important category is confirmed by another international literature review on empirical studies (Darko et al., 2017). The article concludes after an extensive literature review that 'government regulations and policies' is the most important driver (Darko et al., 2017).

Roles and responsibilities of key stakeholders in low-emission construction

Based on the literature on low-emission construction in all the relevant stages of the building life cycle and the literature on supply chain management and green supply chain management, a proposition will be created to suggest the roles and responsibilities of the key stakeholders in low-emission construction projects. The focus is on the project developer but roles and responsibilities of other stakeholders and relations between other stakeholders are important to discuss as well.

The role of the real estate developer

What position does the property developer take in this system? As explained in the introduction, real estate developers play an important executing role in sustainable area development (Heurkens, 2020) According to an article by Elsmore in 2020, developers have to aim for a wider set of values than their own financial values in order to build reputational capital (Elsmore, 2020). Because developers need public approval for their plans it is in their own interest to listen to the public interest. (Elsmore, 2020). This is in line with the internal driver for supply chain stakeholders to adopt green practices (Balasubramanian & Shukla, 2017a)

There are different types of property developers, and one developer can take on several roles in a project. In the book Shaping Places, four roles of a property developer are explained; master or land developer, parcel developer, infrastructure provider or building contractor (Adams & Tiesdell, 2012). Besides these typologies of property developers, three other types of real estate developers could be distinguished. Some developers in the Netherlands are linked to construction companies, some developers are (linked to) investors and you have in dependent developers (Nozeman en Fokkema, 2008). The type of developer could influence the values their values in the decision-making process.

All these types of developers can take on different positions in a project team, but in the basis, they would be responsible for translating demands from investors, the government, and future users to the supply side. Figure 11 shows the central role a project developer takes between the demand and the supply side.

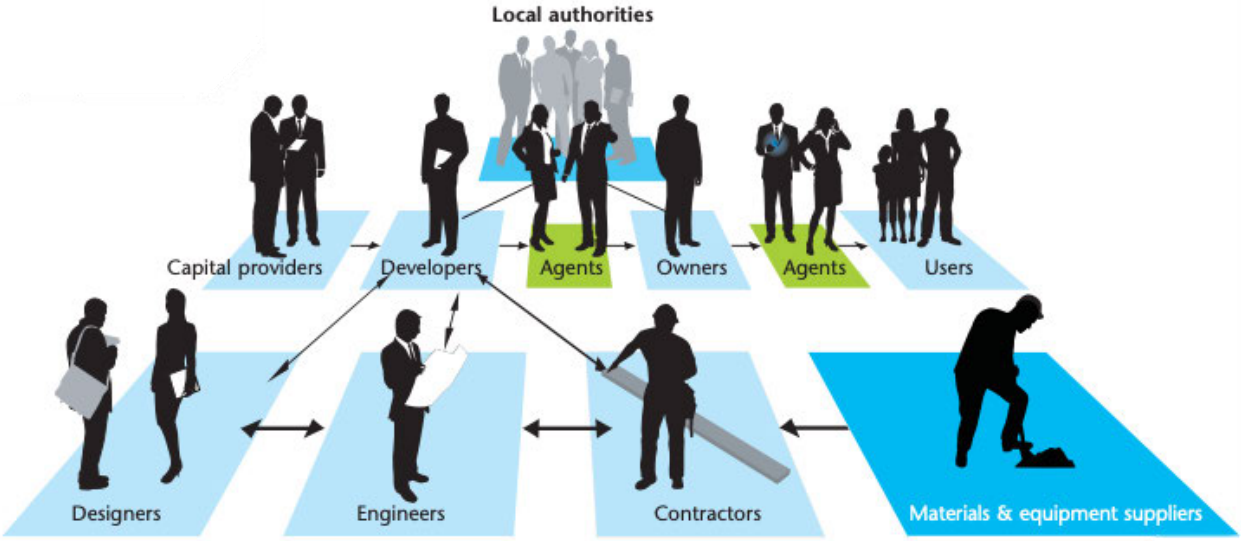


Figure 11, the complex value chain (WBCSD, 2007)

Due to the central role of the developer between the supply and the demand system, as illustrated in Figure 11, the developer has the potential to take on the role as system integrator. According to the literature on green supply chain management, the developer does indeed play an important role in greening the supply chain. According to Balasubramnian & Shukla the developer is not influenced much by other stakeholders but has an important role in mobilizing architects, consultants, contractors, and subcontractors (2017b). The developer has a high influence on the design and procurement of services. The procurement of materials is often the responsibility of the main contractor. Also the influence a developer has on logistics, construction and manufacturing is minimal according to Balasubramanian & Shukla (2017b).

An article on enabling innovation in the construction sector explains what role is important to take the project developer and the contractor. In this article, a case study is done into the implementation of Modern Methods of Construction and lean construction. The client proposed to use timber frames for the projects and waste production was minimized (Ozorhon et al., 2014). In this article the integration of project participants is one of the two most important drivers for implementing innovations. The second driver is effective leadership of the contractor (Ozorhon et al., 2014). The integration of project participants is driven by the developer by partnering with the main contractor based on shared ambitions and regulations. Afterwards partnering with the most important subcontractors and suppliers for innovation needs to be initiated by the developer and contractor (Ozorhon et al., 2014).

Vrijhoef uses nine cases to analyze the possible implementation of integration practices by multiple stakeholders (Vrijhoef, 2011). In the case where the developer acts as supply chain integrator, the organization aims to be in charge of every aspect of the building, since the developer is its own client and wants to be in full control of the final result for his users (Vrijhoef, 2011). It is very important for this developer that project partners share the same ambition and mindset and some functions, like concept design are taken in-house (Vrijhoef, 2011). Whether this is applicable to other types of buildings is difficult to say, since private developers would normally not be their own clients. Vrijhoef & Koskela mention that for housing development, client-led integration would probably come from housing associations with a large portfolio and that developer-led project-independent construction is more likely with commercial development (Vrijhoef, 2008).

In his book Vrijhoef mentions some other topics that contribute to supply chain integration in which developers can play an important role. Clients or developers could enter partnerships with contractors and enter into ‘downstream strategic alliances’ with subcontractors and suppliers. Downstream stakeholders can offer their expertise early in the process. Procurement by using integrated contracts is another way to involve partners for multiple project life cycle stages (Vrijhoef, 2011)

Contractor

According to the article by Balasubramanian et al. the involvement of the contractor in the design stage of a building project is close to nil (Balasubramanian & Shukla, 2017a). The authority of the contractor to influence design choices on, for example, material use is therefore very little according to the article (Balasubramanian & Shukla, 2017a). However, it must be said that this article is primarily focused on the situation in the UAE and that the situation in the Netherlands might differ. Another paper on stakeholder collaboration in green building projects specifically discusses the influence of early contractor involvement (Ferme et al., 2018) In that situation the contractor is involved in the design

stage of the project and should have a more significant influence in this stage. Ferme et al. state that it is beneficial to involve all relevant stakeholders in green building projects, including the contractor, as early as possible so solutions can be implemented in the early design phase (Ferme et al., 2018). However only a few points of the green building credit system used for this research are awarded for material use and those are, according to this article, exactly the decisions that are made by the client/architect even before the early involvement of the contractor (Ferme et al., 2018)

As for green procurement practices, contractors have a moderate involvement (Balasubramanian & Shukla, 2017a). Smaller firms are led by the demands of the project developer and bigger firms tend to have their own requirement, which sometimes exceeds those of the developer (Balasubramanian & Shukla, 2017a).

Some green logistics practices already have a high level of implementation among contractors, especially compared to other stakeholders, since some low-emission practices for logistics are also beneficial for the construction processes, like minimizing the number of transports (Balasubramanian & Shukla, 2017b)

In the literature review on GSCM by Balasubramanian and Shukla (2017), the role of the contractor is rather traditional and not entirely in line with the current position of contractors in project teams. An article that looks into the new position of the contractor, that of early involvement, suggests a great responsibility for the contractor in the transition towards a green construction industry (Holloway & Parrish, 2015) Although respondents in this article rate the impact of the contractor on the overall sustainability below that of the owner and the architect, the author states that the knowledge of contractors on costs, quality and building systems is underutilized in the pre-construction and design phases. When utilized, the contractor has a perfect position to lead the transition (Holloway & Parrish, 2015).

An article that specifically focuses on contractors and their challenges in executing 'green building' projects in Vietnam provides insight into the roles' most important barriers (Tran, 2020). According to this article the 5 greatest barriers for contractors in Vietnam are the lack of standards and regulations on green building, the difficulty in establishing a competent team for these projects, the difficulty in understanding the owner's green goals and contract specifications, the difficulty to find suitable subcontractors and the lack of green building materials and equipment (Tran, 2020).

Consultant

Especially in innovative and challenging projects developers and contractors can hire outside expertise to fill a knowledge gap in their own organization (Li et al., 2012) In 'green projects' this knowledge could be related to environmentally friendly materials and sustainable structural design for example, both important for achieving low-emission targets (Li et al., 2012) This research on the relation of consultants that have experience with sustainability in construction and achieving governmental green certificates is strong. 'Green consultants' can help you achieve green certifications in a cost-effective and smooth manner. These consultants often don't primarily focus on sustainability, since it could also be architects or engineers with additional training in reaching these targets (Li et al., 2012) In a chapter on the roles of the most important stakeholders in green building in developing countries an important role for consultants is confirmed (Huo, 2020). These consultants should be involved from a very early planning

stage. However, their impact will always depend on the willingness of the developer to do make the proposed investments (Huo, 2020).

Architect

One of the most important consultants is the designer or in the construction industry; the architect. When reviewing the different core practices of design, procurement, logistics, construction and end-of-life management the architect has a high level of implementation on green design (Balasubramanian & Shukla, 2017a) In this same paper, the impact architects have on green procurement, -construction & manufacturing, logistics and end-of-life management is very low (Balasubramanian & Shukla, 2017a). However, an article on the lessons learned from emission-free Norwegian construction sites shows that decisions made in early planning and design stages by, among others, the architect has a significant impact on the number of transports of people as well as goods (Fufa et al., 2019). This shows the interconnection between the design and material selection and the effect this has on the logistics and emissions during construction.

Suppliers

There are of course many types of suppliers in the construction supply chain and most of them will have second and third-tier suppliers as well. When looking at the core green practices of a construction project, every practice is relevant to them, since the product stage of a building life cycle already exists of logistics, procurement and production processes and the availability of low-emission products eventually influences the implementation of them as well (Balasubramanian & Shukla, 2017a).

However, the implementation of these practices is lagging with moderate implementation of both core and facilitating green practices (Balasubramanian & Shukla, 2017b). A paper that investigates the perception of both contractors and suppliers on the environmental capabilities of suppliers concludes that contractors can underestimate that capability (Kim et al., 2016). Outside of the construction industry, the relation between the involvement of suppliers in the establishment on the implementation of GSCM has already been investigated. A survey in the package printing industry proves that upstream environmental collaboration with suppliers is positively linked to green procurement, design for disassembly and green design (Vachon, 2007).

Government

The government is an important external factor in the implementation of low-emission practices in construction when it comes to developers and contractors (Balasubramanian & Shukla, 2017b). Rules and Green building regulations put significant external pressure on the developer since they need the public's approval for their plans. Contractors have to hand in plans for the management of the construction site including waste management plans (Balasubramanian & Shukla, 2017b). An article about possible public regulations and incentives in an area development in the Canadian city of Montreal concludes that the government can take on several roles when it comes to promoting green building practices (Voland et al., 2022). Using zoning regulations, tax delays, supplier sharing and bonus density are examples of solutions to take a leading position as municipality (Voland et al., 2022).

4 Emperical research.

Chapter 4 | Empirical Research

Part I: Exploratory Interviews

In this chapter the results of the combined desk research and exploratory interviews will be presented and discussed. The goal of this step is to define a set of low-emission construction practices of which the barriers and drivers for different stakeholders will be reviewed in the case study research. Also, the most important stakeholders involved in low-emission projects will be determined in this step.

Interviewees

A total of five individuals from different organizations were interviewed and asked about low-emission practices that are implemented by their organization. The interviewees were selected based on the following criteria:

- At least four different perspectives from different types of organizations in the construction supply chain should be interviewed.
- The individual has experience with low-emission construction, green construction, sustainability in the construction sector.
- The interviewee has project experience and a sense of feasibility when it comes to construction practices.
- The interviewee has at least 5 years of experience in the construction sector.

A list of the five stakeholders can be seen in Table 5 below. All of the interviewees work at organizations that try to minimize construction emissions in their projects and the participants also work on those projects themselves. Emission reduction is for none of the participants their core task

Participant	Interview date
Architect 1	11-10-2023
Contractor 1	17-10-2023
Developing contractor 1	04-10-2023
Equipment supplier 1	27-09-2023
Developer 1	22-09-2023

Table 5, List of interviewees of the exploratory interviews

Results | Low-Emission construction methods

The interviewees were asked to explain what measures they could think of to limit carbon, nitrogen and particulate matter emissions in designing, procurement, logistics, Construction and manufacturing and end-of-life management. This validated most of the practices on the list in Table 3 most were also mentioned by the practitioners. Table 6 shows whether the interviewees have mentioned the practice or not.

	Developer	Architect	Contractor	Supplier	Developing contractor
Green design					
Environmental impact assessment of design	■	■			■
Provision for the use of prefabricated components			■	■	■
Consideration of materials with high recycled content and low embodied energy	■	■	■		■
Consideration to reduce the use of hazardous materials	■	■	■	■	■
Green procurement					
Environmental criteria(s) are included in material purchase decisions	■		■	■	■
Environmental criteria(s) are included in tendering		■	■	■	■
Green logistics					
Provision of accommodation to employees near project sites			■		
Use of video conferencing					
Employees are encouraged to use shared transport and public transport	■		■		
Materials are transported in full truckload quantities			■	■	
Materials are transported in fuel efficient vehicles	■		■	■	■
Green construction/green manufacturing					
Use of prefabricated components in projects			■	■	■
Use of materials with high recycled content and low embodied energy	■	■	■	■	■
Reducing use of hazardous materials	■	■	■	■	■
Comprehensive waste management plan for project/manufacturing sites			■	■	■
Automation is used for onsite construction/manufacturing activities				■	
Fuel efficient equipment/machinery are used at project/manufacturing site	■		■	■	■
End-of-life management					
Environmental impact assessment during end-of-life demolition of projects	■	■			
Material from the end of life demolished projects is recycled	■	■			■

Table 6, low emission practices mentioned by interviewees (own analysis based on Balasubramanian & Shukla, 2017a)

All the practices but one were mentioned by one or more of the interviewees and are therefore validated. It seems that none of the interviewees would consider employee travel distance as an important measure to limit construction emissions. Some additional practices were mentioned by the interviewees and those are described below.

Developer

In the interview with the project developer, many of the practices in Table 3 were mentioned as well. Some new practices were introduced. One of which was using bio-based materials and especially wood as construction material. As a low-emission design practice the interviewee also emphasized the importance of not using materials at all, which will reduce emissions even more than using sustainable materials. When you do use new materials, the interviewee argued that making sure the materials can be detached from the building and reused in a new project.

In terms of logistics developer 1 explained that using HVO Fuel instead of diesel can save a lot of harmful emissions as well. Some vehicles and some of the equipment can also be electrified to limit the emissions from logistics and construction activities. A material passport could help promote reusability

and therefore limit emissions from future projects, but this wouldn't impact the emissions from the current project.

Architect

In the interview with the architect, the focus was on the design practices and many of the solutions to lower emissions were already mentioned in the literature or the interview with the developer. Additionally to limit the use of new materials as much as possible she mentioned the re-use of existing structures as much as possible. In new projects without an existing structure designing for future use could help by limiting emissions in the future. An example could be to decide to build parking facilities above ground to allow these floors to be used for something else if parking demand fades. As a low emission tendering practice, she argued that early involvement of designers and contractors in the process can help to lower emissions. Some low-emissions design solutions an architect comes up with can be removed from the design when the project is handed over to the contractor. The interviewee stated that it would help to have a conversation about the feasibility of different solutions with the contractor during the design stage to increase the possibility of realization.

To limit emissions from construction emissions the interviewee mentions the use of local materials as a solution to minimize transport movements. Also, careful phasing and integration activities across the project, could help to limit the movements for materials and make sure they come by full truckload quantities. The use of scaffolding and other types of construction equipment could sometimes be minimized by communication between the designers and the (sub)contractors.

Supplier

The supplier that was interviewed is specialized in construction equipment, not materials. Most of the input from this interview therefore relates to low-emission construction and manufacturing. Electrification of construction equipment is essential on the road towards Low-emission construction sites, but this is not without obstacles. According to the supplier electricity grid congestion could be a threat to further electrifying construction sites. However, he argues that most construction sites don't need an industrial electricity grid connection. Peak demands from heavy lifting can be answered by battery containers instead. The supplier was very specific on the type of equipment that can easily be electrified and those that can't. Electric piling equipment is very expensive and therefore there's no sustainable business case yet for low-emission pile foundations. Most other equipment and the site office are already or can become electric in the coming years. On some construction sites where this supplier is involved, electricity is generated by PV panels on the site and with small wind turbines.

Developing contractor

Many of the solutions that were mentioned by this interviewee already are on the list of Table 3. This interviewee specifies how the construction technique and the concrete compound affect the environmental impact. On top of that developing contractor 1 discusses the shortcomings of certificates like BREEAM and LEED. One example he gives on credits you get for construction logistics is that auditing of emitted carbon in construction logistics is rewarded, but no strict carbon ceiling is given. According to him, this doesn't incentivize enough to limit the emissions. He did share some ideas on how to lower logistics emissions to the site, like transport over water and using material hubs in combination with electric trucks for the last kilometres in the city centre.

Contractor

The final interview also confirmed most of the low-emission measures that were already discussed. On top of that the interviewee added that electricity used on the construction site can be generated on site by using solar panels. Ideally, these solar panels are the ones that will be used for the project during exploitation. The contractor also adds a solution to limit particulate matter from construction activities. By using stelcon plates instead of rubble for the construction sites, dust production will be minimized. Choosing stelcon plates instead of rubble also has a positive effect on the number of movements needed for the construction road according to the interviewee and they are reusable for future projects.

Results | Important Stakeholders

Besides naming low-emission construction practices the interviewees were asked to mention the most important stakeholders in these types of projects and why that is. Table 7 shows the interviewees in the top row and their possible answers in the left column.

Stakeholders	Developer	Architect	Contractor	Supplier	Dev/Con	Totaal
Architect						5
Contractor						5
Developer						5
Supplier						3
Consultant						4
Municipality						5
Financier						2
Insurance company						1

Table 7, Construction stakeholders mentioned by interview participants (own work)

Based on this information the key stakeholders in the construction supply chain for low-emission projects don't differ from those used by Balasubramanian and Shukla (2017a). It is interesting though that all parties mention the municipality as a key stakeholder, while the government is just an external driver in some of the literature on green supply chain management (Balasubramanian & Shukla, 2017a). The insurance company was mentioned by the developing contractor as one of the barriers in innovative projects like low-emission construction projects (developing contractor).

> *'CAR-insurance companies are hesitant with timber construction, for two reasons, one is the fire risk and the other one is the water risk.' (Developing contractor 1)*

Framework

The results from the explorative interviews together with the literature research have led to the summary of core practices in Figure 12, divided into five subcategories of low-emission supply chain management. The implications for the individual stakeholders in Table 7 and especially the developer will be investigated through case study research in phase II.

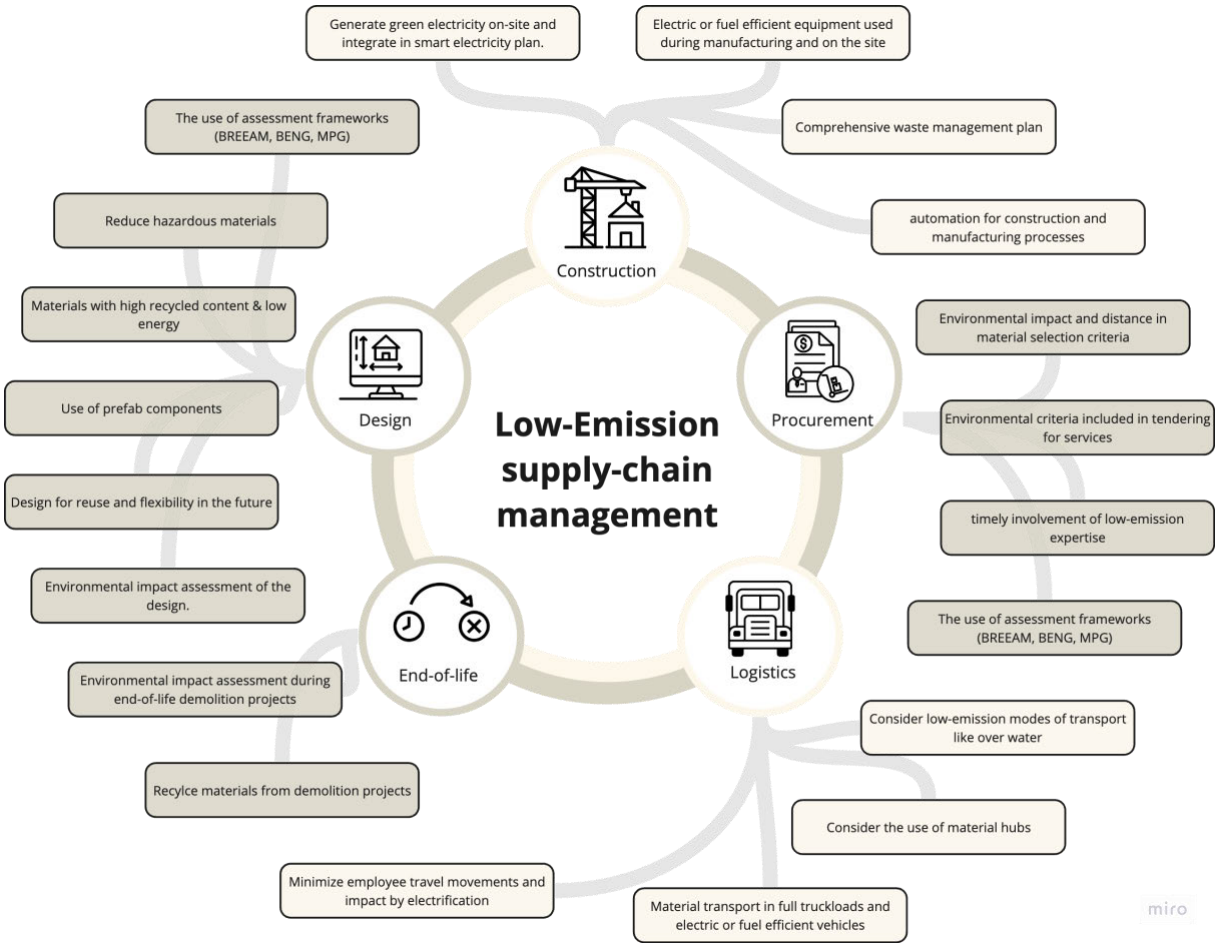


Figure 12, Five low-emission supply chain practices (own work)

Part II: Semi-structured interviews, multiple case study research

To define what construction stakeholders, and especially developers, can do to increase the implementation of low-emission construction practices, four real-life cases have been analysed by interviewing the most relevant stakeholders. First, the selection criteria of the cases will be explained. Secondly, the cases will be described through the most relevant characteristics, without revealing the actual case to protect the participants. Finally, the results from the semi-structured interviews will be discussed.

Case Selection and descriptions

As explained in the introduction, political and public pressure results in a demand for inner-city housing development. To realize a substantial number of new houses in this limited space, building Highrise could be the solution. Cases that are used in this thesis should therefore match these criteria. On top of that the cases ought to deliver some insights in low-emission construction practices. Since perfect emission-free construction projects don't exist yet, multiple cases together should provide insights in the different low-emission construction practices. For this reason, the cases should have applied as many of the practices defined in Part I of this thesis as possible.

Since the hypothesis is that the political context has an important influence on the implementation of low-emission practices and this thesis aims to provide a blueprint for the Dutch inner-city context a stable cross-case relationship should be that all cases are located within Dutch inner-cities. Another typical-case selection method is that all buildings should be over 30 metres high, since that is what is considered high-rise in the ambitions set by the G4 cities (AMS, n.d.; Seawright & Gerring, 2008).

That all projects should be located within the Dutch context however doesn't necessarily mean that the political context is similar. This is not desirable either, since municipalities apply different incentives and have different ambitions which influence stakeholder behaviour and decision-making. Therefore, a diverse-case selection method is applied, so projects won't be in the same municipality. Not only the municipality as an external stakeholder influences the development process. The unique configuration of project partners should also differ per case study project. The projects should be developed and constructed by a variety of developers and contractors in different combinations.

To make sure the projects will be able to provide lessons on low-emission construction the deviant-case method will be applied (Seawright & Gerring, 2008). This means that the projects should overperform compared to the current Dutch standards when on at least one, but preferably more, of the core low-emission practices in Figure 12.

Project A

General

Project A is a combination of a series of row houses connected to a tower around 35 metres high. The building is currently still under construction, but developments started in 2018 The project is a housing development in the first place but also offers room for supporting function, an active ground floor and a rooftop bar and terrace at the top.

Low-emission practices

In this project, significant time and effort was put into the design of the circular façade. The design of the façade is created with circular ambitions. Firstly, the inner structure of the façade is made from timber construction instead of concrete, which has a positive impact on the emissions involved in the production phase as well as on the emissions resulting from logistics to the site.

Secondly, the outer finishing consists of tiles that are mounted to the structure on a system that allows for the tiles to be dismantled from the building and reused in a new project in the future. This helps to prevent emissions in the product stage of future projects. For now, these tiles might have a negative impact on emissions, but since the tiles contain much less material than a standard brick wall, the impact is relatively low.

The third measure that was taken for circularity is that the concrete walls between the dwellings are designed with optional openings in them. If the market shifts towards bigger apartments in the future, this building can be transformed and dwellings can be combined. This means that the building is future-proof and doesn't have to be demolished in different market conditions.

Stakeholder configuration

The developer in this project is part of a large Dutch construction company, but operated independently. The contractor who executes the construction is also part of the same construction company and was involved early through a co-maker agreement. From the municipality, a dedicated project manager was involved in the project, which is part of a big area development.

Project B

General

Project B is currently under construction and construction and will be for over a year. The building reaches up to 19 stories with a height of 50 metres. Just like Project A, this project is a housing development with a gross floor area of 12.000 m2. On the bottom floor, public functions like restaurants are located.

Low-emission practices

Project B is developed to reduce carbon emissions embodied in the materials. For that reason, the main load-bearing structure of this project exists for 90 % of cross-laminated timber. The use of biobased materials and the experience of bio-based construction is increased by limiting the use of gypsum and leaving the structure in sight.

On top of its carbon ambitions, this project was designed with circular principles. The concrete that is poured on top of the wooden floors is separated from the CLT with loose gravel. By doing this the designers make sure that the wooden floors can be reused in the future.

Lastly, this project uses an energy-efficient site office and electric charging stations for cars. Electricity for the office is generated through wind turbines on the roof of the site office. Apart from this office, the use of electrified equipment and logistics is standard.

Stakeholder configuration

The project developer is a private independent developer without connections to big investment- or construction companies. The developer does have a strong connection to the architect of the building. The contractor was involved in the project, because of their track record on wooden constructions. Because of the innovative wooden construction, the structural engineer and wood supplier were involved in an early stage.

Project C

General

Project C is an inner-city development consisting of multiple towers positioned on a parking garage with a rooftop garden. The towers host multiple functions such as a hotel, offices, dwellings and public ground floors with catering.

Low-emission practices

In project C a façade tile has been selected that is mad off 60% recycled waste material. This reduces the raw material needed for production and therefore reduces emissions in life cycle stages A1 and A2. For this project the material usage in the construction is optimized which also leads to a reduction of raw materials and material transport. The third implemented low-emission practice is the electrification of the construction site and the generation of electricity on-site.

Stakeholder configuration

The project is developed by a development combination of two private developers and one developing contractor. This contractor is building the project at the time of writing. The procurement model of the project is traditional apart from the fact that the contractor was involved early. In the interviews a subcontractor responsible for material optimizations was involved.

Project D

General

Project D is a hotel development with 200 bedrooms and was delivered in 2018. Since the other projects are only near construction, this is the oldest of the four projects. The 10-story project is just around 30 metres high and was part of a municipal design competition.

Low-emission practices

This project was awarded a BREEAM excellent certificate after completion. While most of the point are awarded for energy efficiency, some credits are awarded for the replacement of concrete by a modular timber structure. The use of modules for hotel bedrooms, including finished interior, has saved many movements as well.

Stakeholder configuration

The client was an owner of a hotel chain, who participated in a municipal design competition together with an architect. Together with a contractor a structural engineer and the 3D module supplier these parties formed the design team. Some suppliers were hired directly by the client since the client had worked on previous hotel developments with these (interior) suppliers. The process was managed by a project management firm who acts as delegate of the client.

List of participants

Table 8 shows a list of the participants in the case-study research and the date of the interview.

Project	Participant	Interview date
Project A	Developer	22/09/2023
	Contractor	01-11-2023
	Municipality	06-11-2023
	Architect	14-11-2023
Project B	Developer	09-10-2023
	Contractor	06-10-2023
	Municipality	26-10-2023
	Chief constructor	03-11-2023
Project C	Developer	27-10-2023
	Subcontractor	10-11-2023
	Municipality 1	07-11-2023
	Municipality 2	08-11-2023
	Contractor	13-11-2023
Project D	Contractor	10-11-2023
	Clients' delegate	08-11-2023
	Supplier	13-11-2023
	Municipality	16-11-2023

Table 8, list of interviewees case study projects.

Method of analysis of semi-structured interviews

The semi-structured interviews from the case studies will be read and carefully coded in the same way. The codes will be part of a specific category that is clear from the beginning. To answer the last three research questions, it is important to know what core Low-Emission practices were applied in the case study projects and why it was possible to apply these practices in this specific case. Secondly, it is important to code the most important barriers and drivers for the implementation of low-emission practices. Thirdly it is important to link the practices, barriers and drivers to specific stakeholders to be able to determine the position of the developer in the implementation of low-emission practices. After the individual interviews have been read and coded the cases will be analyzed using Atlas.ti. To be able to draw conclusions that are generalizable the individual cases will be analyzed based on the following three topics first:

- Implementation of low-emission practices in the supply chain and the roles of different stakeholders.
- Barriers and drivers to implementing low emission practices in the supply chain.
- The position of the real estate developer in the implementation of low-emission practices.

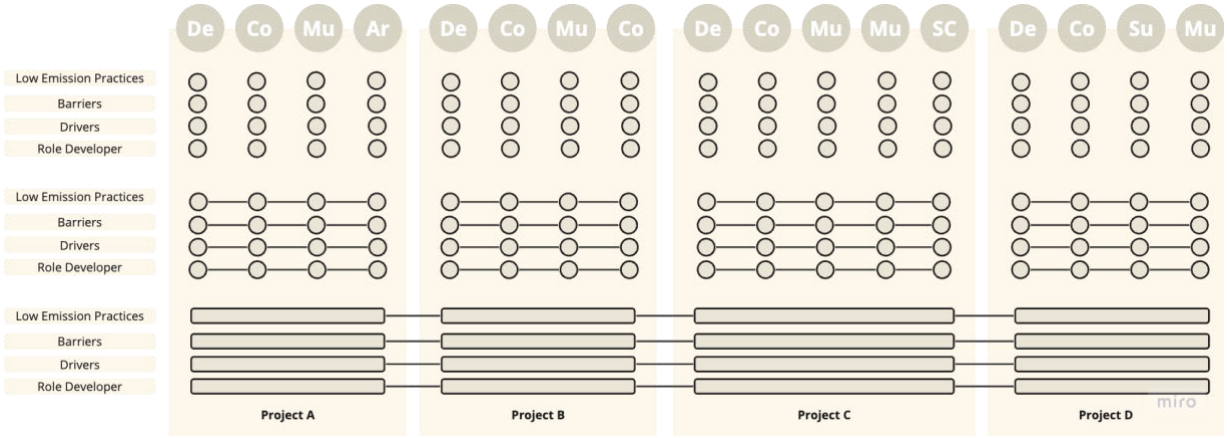


Figure 13, Analysis of in depth interviews of multiple-case study research (own work)

After the analysis an individual report can be written per case. These reports together will be used to look for cross-case similarities and differences that stand out (Yin, 2018). Finally the cross-case analysis will be compared to findings in literature and tested with an expert panel before conclusions can be drawn. An overview of how the individual interviews will be used to draw cross-case conclusions on the different topics can be seen in figure 13 from top to bottom. This is based on the multiple case study analysis seen in figure 14 (Yin, 2018)

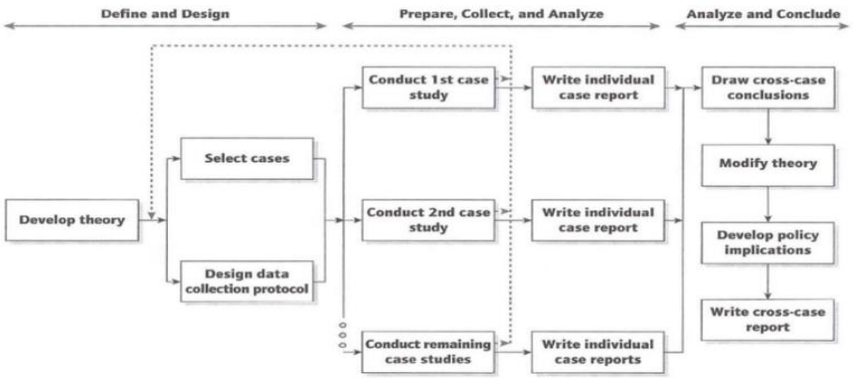


Figure 14, Multiple case study analysis (Yin, 2018)

In-Case analysis | Project A

Low-Emission Design

The stakeholders in this project made a few design choices that have reduced emissions related to material production. Firstly, they have selected a collective heat pump for the entire project, which leads to a reduction of material compared to the 85 smaller heat pumps the project would have needed otherwise (Developer A). On top of that, the innovative Thermal Energy System doesn't require wells to be put in the ground, which limits the groundwork and therefore construction emissions (Developer A).

Secondly, the design team consisting of the architect, developer and contractor has selected a lightweight façade tiling system. This weight reduction compared to traditional construction results in emission reduction during construction and logistics (Zhang et al., 2013). The light tiles allow for the façade construction to be made of timber instead of prefabricated concrete (Contractor A). The façade system is also circular, in a way that the tiles can be removed, and the system can be applied on a different building, resulting in less weight and reduced need for material production in the future. According to contractor A, this façade has its difficulties, but the interviewee also states that it might be the solution for the future:

> *'If you put the technological concerns and challenges aside, you think; yes, it is really a façade for the future. It is demountable and it contains 8 times less clay than in traditional brick wall construction. The clay needs to be collected and baked in the oven, so it adds up" (contractor A)*

Thirdly, the buildings' floor plan is flexible if the market demand shifts towards bigger dwellings. In some of the structural walls, steel reinforcement-free zones are created in the walls, which makes it possible to combine multiple smaller dwellings in the future (Architect A). According to Architect A, this was brought up by them and accepted by the developer and contractor.

Low-Emission Procurement

The developer and the contractor signed a co-maker agreement, which is a way to involve the contractor in the design process. After this process, the developer will most likely award the construction to the contractor involved in the design process (Developer A). The contractor must build the project according to the legal documents that were produced in collaboration with the architect, developer and other advisors and is therefore legally bound to the specific materials and building systems as well (Developer A).

The selection of the circular façade system was driven by esthetical and financial considerations (Contractors A, Developer A). He explains that the database of low-emission materials is not sufficiently filled yet (Contractor A). However, the contractor explains that the distance from the supplier to the site is starting to gain attention in their organization:

> *'I hear people say; Why would you select a brick from Germany, while there are perfectly fine bricks available in the Netherlands which have to travel 800 km less.' (Contractor A).*

According to the architect and contractor, the biggest impact a developer can have is in setting ambitions and forming the project coalition (Architect A, Contractor A).

> *"It has to do with formulating the right ambitions for your long-term goals as a developer and selecting the right parties to achieve those" (Contractor A)*

> *"The client can formulate quality standards" "The client should play a guardian role for ambitions" (Architect A)*

Low-Emission Logistics

Neither of the involved parties has focused on reducing the logistics emissions related to the project. The municipality however did focus on logistics around the bigger area development, but this was to limit nuisance and improve safety in the surroundings (Municipality A). The timber façade instead of prefab concrete and the tiles instead of bricks result in a significant material and weight reduction which leads to a reduction in logistics emissions as well (Zhang et al., 2013).

Low-Emission Construction & Manufacturing

Both the developer and the contractor explain that they will start using and prescribing low-emission fuel for all their construction processes in the future, but that this project is still executed with traditional diesel machinery (Developer A, Contractor A).

According to the contractor electric equipment is sometimes still limitedly available and this has its consequences for the contract sum; 'Diesel is cheap and if it is necessary to replace some of the diesel equipment, the extra costs have to be negotiated with the developer" (Contractor A).

Low-Emission End-of-life management

There were no existing buildings on the plot, so this did not provide the option for reuse. While the stakeholders involved the end-of-life stage in their design, this is discussed as low-emission design practice.

Barriers

The timber construction façade increases risk during construction, because it cannot not become wet during construction (Developer A). Another technological barrier was the limited room on the construction site, which lead to complicated construction logistics even without low emission ambitions (Developer A). According to the contractor realizing an emission-free construction site would not be possible, since not all equipment, like some cranes and piling installations, can be electrified yet (Contractor A).

On top of that the project was already financially challenging and therefore it becomes a delicate balance between financial feasibility and low emission ambitions (Developer A). When the developer would prescribe certain equipment, they explain that the contractor would charge the additional investment on the developer (Developer A). Therefore, it is difficult as developer to enforce the use of electrified equipment.

A political barrier is that the emissions from logistics and the investments that need to be done by developers to achieve a certain level of emission reduction in these steps will not be visible in the MPG score (Developer A).

The project team have to make decisions for certain social and environmental sustainability goals per project, not only for financial reasons, but also since there's often not more than one person involved in the project from every partner. This means they need to dedicate limited time available to manage reaching these ambitions (Developer A).

An institutional barrier formed by the developer is the strictness of delaines. According to the architect, low emission design and construction takes more time than traditional methods and the client must realize that when formulating the ambitions (Architect A).

Barrier	Type
Concrete favorable over timber in wet conditions	Technological
Shortage of electrical equipment	Technological
Limited space on-site, so challenging construction logistics	Technological
Financially challenging project	Economical
Developer would be charged extra for prescribing electrified equipment	Economical
MPG would not take all sustainable measures into account	Political
Lack of political ambition to limit emissions	Political
Lack of environmental ambition from the start	Institutional
Strict deadlines set by developer	Institutional

Table 9, Perceived barriers to implementation of low-emission practices in project A

Drivers

The first driver I this project was raised by the developer and is about the mindset of the parties involved in the project. Both the contractor, the architect and the developer mention that the mindset of the involved parties is often the most important driver (Architect A, Developer A, Contractor A).

> *But I think it's mostly in people's drive and feelings. We really have to want to do things differently. And If we all have the willingness then a lot is possible and if we all implement innovations in every project, then we are going to gain more and more experience and then slowly it becomes more and more commonplace. (Developer A)*

A political driver mentioned by the developer is the close collaboration with the dedicated project manager from the municipality. This person was flexible and available to think about solutions together with the design team (Developer A).

The contractor mentions another political driver. Namely, the municipal GPR score did stimulate the selection of the circular façade system (Contractor A). However, the solution was driven by costs more than the sustainability ambitions of the design team (Contractor A).

The interviewee from the municipality explains why these parties were awarded the plot and that emission reduction during the construction process was not one of the topics (Municipality A). This lack of incentive from the municipal level could form a barrier to optimal implementation.

Driver	Type
Mindset of involved stakeholders/intrinsic motivation	Institutional
Close collaboration with dedicated project manager municipality	Political
GPR score set by municipality	Political
Cost reduction	Economical
Clear ambition from the start	Institutional

Table 10, Perceived drivers for the implementation of low-emission practices in project B

Influence of the developer for framework

The developer in this project used a co-maker agreement to involve the contractor early in the design process. This is beneficial for the feasibility of the design but was not a real sign of integration by the developer since the responsibility over the project is officially handed over to the contractor at the start of construction. What was positive about the developer in this case was that it personally came up with the idea to involve a specialized party for the thermal energy system. According to the architect it would have been more logical if this would have been suggested by the installation consultant (Architect A). Parties feel that a lack of environmental ambitions from the start have been a barrier for further implementation of low-emission practices.

In-Case analysis | Project B

Low-Emission Design

Project B's main load-bearing structure is designed in timber. This was a decision made from the start by the developer and architect (Developer B). A close collaboration between the architect and the developer was very important according to the developer.

> *' The chain was integrated between the architect and the developer, so we could design and calculate the costs simultaneously to see the effect of certain design choices.' (Developer B)*

According to the contractor, the design of some details and connections was not finished before construction started. This has led to delays during construction (Contractor B). One example is the way the gallery floor is attached to the building. This part of the design was executed in timber, but there are no guidelines on this type of construction, which has led to a lot of extra consultations from both the contractor and the municipal side (Contractor B).

> *'Normally the execution team doesn't have much to do with the municipality. .. It is just a fraction of your process, but with timber construction municipal approval is the common thread in the project.'* (Contractor B)

The structural engineer was involved from the beginning before the sketch design. This is normal in innovative projects and, since it was a plan from the start to build this high-rise structure out of timber, it was a logical decision (consultant B). The structural engineer explains that in timber construction the type of connections needs to be clear from the start and that you can involve the timber supplier right from the start or after the design is definitive but not during the design process (Consultant B). According to the consultant, timber suppliers are often involved during the design process, but some suppliers are not used to be part of a design team, which can lead to delays (Consultant B). Structural engineers and architects together can design the connection themselves and ask suppliers to work with the completed building specifications (Consultant B).

Low-Emission Procurement

Before the private sector stakeholders were involved in the project, the municipality planned to reserve the plot for the development of a sustainable building. Although the municipality did not expect or demand timber high-rise construction, it shows that the municipality was open to an innovative initiative at these locations (Municipality B).

According to the developer, the contractor involved must have the experience and courage to take on an innovative project like this one (Develop B). However, the developer thinks that some responsibilities can be transferred from the contractor to the supplier in the case of timber construction. Compared to traditional construction the main contractor doesn't play the same coordinating role, since the supplier builds the entire timber structure including the warranty (Developer B).

The supplier has a very important position within the projects since they were in the position to demand a specific structural engineer for the project, with whom they had worked together before. This led to

a second structural engineer, which was not an ideal situation (Contractor B). According to the structural engineer, involving the supplier early in the process, is not always beneficial, since suppliers don't have design experience like structural engineers do and engineers can design in wood without the help of suppliers (Chief Constructor B).

Low-Emission Logistics

The municipality has reviewed the possibilities to limiting logistics movements as much as possible, using electric vehicles for delivery to the building site or even using transport over water (Municipality B). In the process, it became clear that the project already was very challenging and therefore the demands were dropped (Municipality B).

> *"In projects, we ask parties about the possibilities to reach the construction site with electric vehicles and sometimes we explore the possibilities for transport over water" (Municipality B).*

The developer and architect calculated the distances materials had to travel to the site and are developing this calculation tool further for the future (Developer B, Architect B).

Low-Emission Construction & Manufacturing

Since the timber elements are fabricated in a factory and therefore the production process on-site is limited. Electric equipment for the processes on-site is not used for this project (Developer B, municipality B). However, the site office is equipped with wind-turbines and solar panels which generate electricity (Contractor B). The developer explains that emission-free construction sites would be the next step, but the focus now was on reducing carbon emissions from the production of concrete (Developer B).

The contractor does try to reduce waste on the site and pre-fabrication can help with that. Although the contractor is a bit skeptical, since waste production will, according to him, just take place in the factory instead of the construction-site (Contractor B). The contractor has focused on 'low-hanging fruits'.

> *'Spare concrete is poured into molds to make road barriers and there is a unit next to the site office that generates electricity with solar panels and wind-turbines.'. (Contractor B).*

Low-Emission End-of-life management

In terms of end-of-life management the contractor and developer explain that e special floor is used in the building. The screed is poured on recycled gravel (Contractor B, Developer B) This means that the timber elements can be removed from the creed after its useful life in this project. The timber can be reused in the future.

Barriers

One of the barriers to building with timber is the shortage of timber suppliers. Therefore, the developer had to contact potential timber suppliers early in the process since they receive many requests and can't honor them all (Developer B). The contractor confirms this and explains that is makes them dependent

on the supplier compared to traditional projects. Since this is such a limitation, it can become the common tread in the project (Contractor B)

The same developer also mentions the lack of awareness and mindset to limit construction emissions in municipalities (Developer B).

> *'Sometimes they say it is above the law, but that is nonsense since the Paris Agreement was also signed by the Dutch government, so why would keeping to those standards be above the law' (Developer B)*

Another political barrier explained by the developer is the difficult and lengthy permit procedure. He explains that it takes the project partners a lot of time, but also explained that it is a difficult problem to resolve since the project management and permit departments are strictly separated within the municipality (Developer B). The innovativeness is costly, since the team has had eight second opinions on this project (Developer B).

Another political barrier is related to the MPG calculations that are used in the Netherlands. According to the developer, these calculations are like black boxes, it is not clear what the exact input should be and therefore different parties use different methods to do the calculations (Developer b)

The contractor also explains the extra costs that are linked to the selection of timber as construction material. The financial return can become small, so the client might have to make the decision to lower the ambitions at some point (contractor B). The developer confirms this and explains that their company is interested in maximum value instead of profit. Therefore, they have a different view on the costs of some design choices (developer b).

Barrier	Type
Shortage of timber suppliers	Technological
Lack of awareness and the right mindset at municipality	Political
Delay in permit procedure	Political
MPG calculation method limitations	Political
High consultancy costs	Economical
High cost of innovation	Economical
Underdeveloped timber supply chain	Technological

Table 11, Perceived barriers to the implementation of low-emission practices in project B

Drivers

Since there's a shortage of timber suppliers, involving one early in the process can drive your process. These suppliers want to produce their CLT walls and floors during construction, so they need to plan carefully (Developer B). Another important partner according to the developer is the contractor. The contractor has to have courage and experience to step into an innovative project like this (Developer B). The Paris agreement is an important political driver for the use of timber as construction material.

'If you want to follow the Paris Agreement, than you have to start building with bio-based materials. You can't just keep on building with concrete. I fully believe that.' (Developer B)

The developer also mentions that the level of knowledge of your partners is very important. They plan on working together with the same project coalition in the future since they've learned a lot together (Developer B). As discussed at the barrier paragraph intrinsic motivation of the partners to limit emissions is a drier as well (Developer B).

A political driver that can increase the feasibility of low emission project is the amount that the municipality will ask for the land-sale price. According to the municipality, they wanted to see whether they could deviate from their standardized land-sale policy (Municipality B). Another political driver can be the direct contact for the project team from the municipality and whether they are willing to speed up internal procedures at the municipality (Municipality B).

Driver	Type
Early involvement of supplier	Institutional
Contractor with the right courage and mindset	Institutional
Paris agreement goals	Political
Knowledge of project partners	Institutional
Intrinsic motivation of parties	Institutional
Include environmental criteria in land price	Political
Dedicated project manager municipality	Political

Table 12, Perceived drivers to the implementation of low-emission practices in project B

Influence of the developer for framework

The developer had a central role in this project since many disciplines were involved early in the process by the developer. Close collaboration with the architect, early involvement of the contractor and early involvement of a timber supplier contributed to the feasibility of this project. The developer has the intrinsic motivation to show a new way of project development not only in terms of sustainability, but also socially (Developer B).

'Project B is not only constructed in wood. The project also contributes to biodiversity and half of the dwellings will be mid rent. Project B is more like new way of life"(Developer B)

In-Case analysis | Project C

Low-Emission Design

According to the developer, low-emission design choices are limited in this project, since the design was made in 2015, when emission reduction was not under their attention yet (Developer C). In collaboration with the contractor, the design team has selected a timber construction for the façade in combination with stone strips (Developer C). The strips are made off 60% construction waste, which leads to a significant reduction in the need for raw materials (Developer C). This façade system was innovative and new apart from its low-emission potential. Therefore the municipal approval was difficult to obtain by the contractor, which has lead to delays and extra costs for tests and consultants (Municipality C1, Municipality C2, Contractor C).

The Developer explains that the load-bearing structure could not be executed in timber because of the complexity of the shape and the function mix. Concrete offers more flexibility than timber in that case. Another technical aspect that leads to the decision to use concrete was that mass was needed to compensate for vibrations of the railroad next to the building (Developer C).

Although they built a traditional concrete structure, the contractor hired a subcontractor for the foundation that uses optimization software to specify the dimensions of the construction and limit the amount of concrete used for the building (Contractor C). This has led to the reduction over 2000 cubic meters of concrete (Subcontractor C). The contractor, chief constructor and the subcontractor together have decided to optimize the construction without the influence of the developer and architect (Subcontractor C). This was due to the intrinsic motivation of the contractor since they have realized that 80% of their emissions as a company result from the use of concrete the objective is to change that (Contractor C).

> *'The sustainable solutions in this project are really brought up by the contractor' (Contractor C)*

Low-Emission Procurement

In the selection of the stone strips the contractor was the one to gather the different options. The developer eventually is the one to decide and he is advised by the architect. Although the contractor had indicated that this stone was the best option in terms of emission reduction, costs and esthetics were the main cause of selecting this stone (Contractor C, Developer C).

The subcontractor explains that material reduction leads to an emission reduction in production and logistics, but that most clients are driven by cost reduction in the first place. What is important in this specific case is that the chief constructor is hired by the same party, the contractor, as the subcontractor. This is beneficial, since the chief constructor will be pushed by the contractor to collaborate with the subcontractor to optimize the use of materials, which would not come naturally if the chief constructor was hired directly by the developer, since the developer would not feel the direct financial benefits of material reduction (Subcontractor C)

> 'In the end the important thing is who is hired by whom?" (Subcontractor C)

Low-Emission Logistics

None of the interviewees indicate that effort was made to reduce emissions from logistics to and from the construction site. However, the optimization of the foundation has saved 171 trucks according to the subcontractor responsible for the foundation (Subcontractor C). In the future the contractor will prescribe low emission HVO fuel internally and for subcontractors (Contractor C). For this project, neither of the parties nor the municipality have given extra attention to the emissions resulting from construction logistics.

Low-Emission Construction & Manufacturing

On this site, an Aerius calculation had to prove the environmental impact of the construction activity, so this activated the contractor and municipality to be critical on the logistics and construction site emissions of nitrogen and the effects on the nearby natura 2000 area (Municipality C2, Contractor C). After it became clear that the impact would be minimal, in the worst-case scenario, the municipality and developer did not set any other level of ambition than the national minimum (Municipality C2).

The contractor has decided to use this project as one of its sustainable pilot projects and therefore minimized construction emissions on-site to a minimum without any pressure from other stakeholders (Contractor C). Three measures were taken to reduce construction emissions. Firstly, electricity was generated on the site office, using solar panels, the office was energy efficient, and the equipment was almost completely electrified. Secondly, the electricity use was measured live to plan peak usage and be able to work with a small electricity connection to the site (Contractor C). This is beneficial, since some sites cannot get an industrial electricity connection due to the growing concern grid congestion in the Netherlands (Contractor C) The third measure was the circular façade system discussed in the previous paragraph, which was delivered without packaging:

> *We have limited packaging to a minimum by asking the supplier to deliver the stones in recycled shopping crates" (Contractor C)*

Low-Emission End-of-life management

There were no existing structures on the plot that could be reused by the development combination. However, in terms of end-of-life management. The façade tiles are made off 60% recycled content. Just like in the other projects, this is considered a design decision.

Barriers

One of the barriers in the implementation of low-emission practices in this project is the lack of awareness at the municipality for this topic (Municipality C1+2). Instead of driving sustainable decisions, the municipal approval for de innovative façade system was a barrier, causing delays for the contractor (Contractor C). Another barrier was formed by the unwillingness off the investor to financially contribute to the innovative façade solution. Therefore, the developer and contractor had to share the extra costs for the additional investment. (Developer C).

A barrier for the foundation subcontractor to fully transition towards electrified equipment are the high investment costs and the limited generations available. According to him first generations of electrified piling equipment is just on the market, but fully electrifying your business right away would be unwise, since newer generations would probably have better presentations and more affordable (subcontractor C).

Barrier	Type
Stacking functions in difficult shape	Technological
Timber construction and weather conditions	Technological
Lengthy permit process due to innovative façade	Political
Investor doesn't invest in sustainability	Institutional
Shortage of equipment (electrical)	Technological
Sustainability is container concept	Informational
Lack of rules and regulations from municipality and client	Institutional

Table 13, Perceived barriers to the implementation of low-emission practices in project C

Drivers

According to the developer the contractor was incredibly motivated to electrify much of the equipment and very proud to show that equipment to visitors (Developer C) An important driver in optimizing the concrete pile foundation was the cost reduction this would result in for the contractor and the subcontractor (Subcontractor C). An organizational driver behind this cost driven decision is that is essential that the subcontractor optimizing the construction should be hired by the party that also benefits financially from the optimization (Subcontractor C).

In the end, the biggest driver in this project was the intrinsic motivation of the contractor, since the other stakeholders were not as involved to lower emissions from the project. The contractor has selected this project to test some sustainability goals from which the rest of the company can learn (Contractor C). This contractor intrinsic motivation is also driven by improved working conditions that electrifying the equipment can offer to the workers on-site (Contractor C). The contractor explains that they limit the objectives per project since sustainability is a container term according to him (Contractor C).

Driver	Type
Intrinsic motivation contractor	Institutional
Improving working conditions	Institutional
Cost reduction by material optimization	Economical
Clear definition of sustainability objectives	Institutional
Optimization software	Technological

Table 14, Perceived barriers to the implementation of low-emission practices in project C

Influence of the developer for framework

In this project the developer has not been responsible for the integration of the supply chain or increased implementation of low-emission practices. The contractor explains that these low-emission practices were implemented completely because of him:

The subcontractor responsible for optimizing the foundation explains that early involvement of them on the project, after the preliminary design can be helpful to optimally use their expertise (Subcontractor C).

> "That is right, the sustainable objectives are implemented by the builder alone. …. The developer did not really voice its opinion on that topic." (Contractor C)

In-Case analysis | Project D

Low-Emission Design

In this building, not only the façade or the main load-bearing structure, but the interior as well, is made off bio-based materials (Contractor D). The concrete used for a small part of the building contains 30% recycled concrete.

> *'That was ambitious back then. This did not exist yet, so we had to pay a premium for it. Now this has become quite standard' (Contractor D)*

The client and architect wanted to achieve a BREEAM excellent certificate, which has led to the design optimizations (Contractor D). Since the building had many standardized rooms, part of the building is made of 3D modules. Naturally, this has a big effect on the construction and manufacturing phase, but for the design phase as well. It meant that the supplier of these modules was part of the design team and that the design must be finished in detail before construction began (Clients' delegate D). A special consultant was hired for the design process to advise the design-team on possible BREEAM optimizations to achieve more credits (Contractor D).

> '*The architect and us had to deliver a lot of documents, so to streamline that, the consultant was hired' (Contractor D).*

Low-Emission Procurement

The land is owned by the municipality and a design competition was organized to determine the party who could lease the ground and realize their plans. The client was interested in the location for his hotel and found out that the architect already made analysis of the location. Some sustainability aspects could be awarded credits, although most of these credits relate to the operation of the building and not the construction phase (Municipality D).

The chief constructor was involved through the architect since they had previously collaborated with each other. The contractor was selected directly by the client to take part in the design team (Contractor D). The last party to be part of the design team was the supplier of the wooden modules, whose involvement in the design team is inevitable due to the nature of modular construction (Supplier D).

The procurement of materials and services was strict, because the BREEAM excellent criteria should be met at the end of the project (Client's delegate D). Therefore, a specialized consultant was involved to streamline the BREEAM process. All subcontractors and suppliers also needed an ISO certificate to assure the quality of the organization (Contractor D).

Low-Emission Logistics

The biggest logistical emission reduction was caused by the decision to finish the interior of the modules in the factory (Contractor D). Since all the materials and people do not have to move to and from the

site, this limits the emissions in the city. The hypothesis is that the off-site production process is also more streamlined and therefore reduces the overall movements of goods and people (Supplier D).

The supplier explains that the concrete floor slabs they use to produce the modules are transported with electric trucks nowadays, but that was not the case yet during the construction of this project (Supplier D).

> *'These trucks don't exist for very long, so the bigger logistics companies are now starting to buy one and that is much more expensive as a traditional one'* (Supplier D).

The municipality explains that there were no guidelines or regulations to limit construction logistics. They did stimulate transport over water but had to let that go, since the load capacity of the dock was not sufficient (Municipality D).

Low-Emission Construction & Manufacturing

Low emission and construction practices were not a real topic in this project since it has been a long time ago. Construction started in 2016, when there was little to no focus on construction-site emissions.

> *'The past 5 or 6 years a transition has taken place and now there is much more attention for this topic than back then.' (Clients' delegate D)*

Much of the emissions on-site were reduced by choosing modular timber construction, but the rest of the construction process was traditionally built with diesel generators and cranes (Contractor D)

Low-Emission End-of-life management

The timber modules can be taken apart at the end of the building's life cycle, but as explained that is considered a low-emission design practice and not end-of-life management. As with the other projects, there was no building on the site before this development.

Barriers

One of the most important barriers in achieving the desired BREEAM certificate is the cost that come with innovation (Contractor D). The other barrier linked to these innovations is whether the contractor can build it technically or not. This has given some discussion between de architect on one side and client and contractor on the other side (Contractor D). This is an example of an institutional barrier.

Another barrier according to the client's delegate was technological and had to do with the level of detail the design needs to have before construction starts. According to modular construction can be quick, and it was, but every element must fit perfectly on top of the other and that leads to a high level of detail (Client's delegate D).

A technical barrier of building with prefabricated modules is that is doesn't offer all the flexibility you might want to have (Supplier D). The supplier offers a certified system in terms of for example structural- and fire safety and this will not be valid when the structure of the modules is changed (Supplier D).

Barrier	Type
Financial feasibility	Economical
Level of innovation for contractor	Technological/institutional
Level of detail in early design phases for modularity	Technological
Lack of flexibility in design modularity	Technological
Timely administration process BREEAM certificate	Institutional
Unmature technology for long-distance electric logistics	Technological

Table 15, Perceived barriers to the implementation of low-emission practices in project D

Drivers

The biggest driver for the implementation of low-emission practices according to the contractor was the BREEAM certificate (contractor D).

> *'Obtaining an BREEAM certificate contains two steps. The first is the design and the second one is construction. You cannot select different materials just like that during construction, because than you will not make it.'* (Contractor D).

The BREEAM certificate did not come by itself but is the result of the ambitious collaboration between the client and the architect, so you could say that the most important driver is an organizational one, the design teams' clear ambition. This is confirmed by the municipality, who states that the level of ambition of the architect and the developer were a driving force behind the implementation of low-emission practices (Municipality D)

The municipality did not oblige the client to build a very sustainable hotel, so in that way they did not offer an important driver. However, since the right to develop the hotel by the client was won in a design competition, the municipality had to confirm that the result would match the winning design. Otherwise, other contestants could lodge an appeal against the development. In this way, a design competition can spark ambition and hold the winning parties to their promise (Municipality D). Lastly, according to the delegate, innovative projects like this cannot be realized without a flexible and experienced team. Some creativity was required of all stakeholders (Client's delegate D).

Drivers	Type
Using a certificate (BREEAM) to streamline low-emission practices in every step of the supply chain	Institutional, informational
Ambitious collaboration between client & architect	Institutional
Winning design competition led them to keep their promise	Political
Selection of partners based on prior experience and collaborations.	Institutional
Special consultant for certificate	Institutional
Flexible team	Institutional
Continuity in municipal project management	Political

Table 16, Perceived drivers to the implementation of low-emission practices in project D

Influence of the developer for framework

The developer has approached the architect to participate in the design competition, because the architect had already created a vision for the location some time earlier (Municipality D). According to the contractor, the BREEAM certificate was a hard demand from the developer, so the developer had embraced the vision of the architect (Contractor D)

According to the municipality the role of the developer was an important driving factor behind the high level of ambition and maintaining a good relationship with surrounding neighbors and de municipality (Municipality D)

The developer in this project has taken full control over the supply chain and hired some subcontractors directly as well. These subcontractors were hired directly since the client is a hotel owner and knows these subcontractors from previous hotel developments.

Cross-case Analysis

Low emission-design

What stands out from the analysis is that there is a difference in the level of implementation of low emission design practices between projects A and C and project B and D. The latter have a higher level of implementation, since not only the façade, but the load bearing structure as well was replaced by timber. In projects B and D the ambition was set from the initiative to build in timber and in both projects the architect and developer had a close collaboration and a shared ambition to realize a project with low-impact materials. In all four projects, the low-emission design practices were initiated by the partners in the design team and not demanded by the municipality or higher government. Since there were no regulations guiding the stakeholders in the design process.

Projects C and D show that even when constructing with hazardous materials like concrete, emission reduction can be accomplished by increasing the amount of recycled content or optimizing the amount of material with the help of computer software. The interviews with stakeholders form project B, C and D show that inner-city projects with mixed functions can be challenging to design in timber. Since different functions have to be stacked on top of each and concrete offers the designer more freedom in the floorplan (Developer C). In project D, concrete and steel construction is used for those parts of the building where a wide variety of floorplans is created in a non-rectangular shape (Contractor D). In project B concrete is used to offer stability, because of the height of the structure (Developer B). Complicated, floorplans, diverse function-mixes and high-rise are common in inner-city projects, so this confirms the scope of the thesis.

Low-Emission procurement

A similarity between the four projects is the early involvement of the contractor in the design process. In project A the contractor is involved through a co-maker agreement, in which the developer and contractor have the intention to collaborate during construction as well (Developer A). Developer B explains that it is very important to select a contractor with the right mindset and courage (developer B). In Project C the contractor was involved just before the definitive design (Contractor C). In project D the contractor was involved by the client to join the design team right after winning the design competition (Contractor D). In projects B and D where the ambitions to build timber high-rise (Project B) and a BREEAM building (Project D) were clear from the start the contractors could be selected on prior experience with these types of projects. Contractor D was involved by the client, since they had previously worked together, and they had delivered BREEAM buildings before (Contractor D).

In project B and D the timber supplier and timber module supplier were involved early on in the process. One the one hand, because timber suppliers who can deliver the amounts necessary for these projects are scarce. On the other hand, since involving them in the design process can limit risks linked to the technical innovations.

For the procurement of materials, it's important that environmental criteria are part of the selection criteria. In project B the developer had the ambition to build a timber construction, but left some of the interior walls to be built traditionally. The BREEAM certificate in project D included the low-emission

criteria in the purchase of all materials in the design. Also, subcontractors and suppliers had to be certified (contractor D).

Low-emission construction & manufacturing

In the cross-case analysis, it becomes clear that the level of implementation differs quite substantially between the four projects and this is not related to the level of implementation of low-emission design practices. Project C has a very high level of low-emission construction practice implementation, but doesn't excel in low-emission design practices. In project A no attention was given to the reduction of emissions on the construction site. Developer A explains that they do not ask contractors to use electric equipment, since the extra costs would be transferred to them (Developer A). Developer B explains that it depends on technological advancements in the market.

> *"Whether a contractor is going to use electric equipment depends on the state of technology at that moment." Developer B*

However, at Project C, the contractor has set the ambition themselves and explained that the additional costs are within acceptable margins for them (Contractor C). In both cases where low-emission construction practices were implemented, project B and Project C, the initiative for it came from the contractor and there was little to no involvement from other internal or external actors in those decisions.

In Project C smart use of the electricity capacity by measuring the actual usage instead of the maximum usage is useful in making the electrification of construction sites feasible on locations where net congestion can play a role (Contractor C). This was also confirmed in the exploratory interviews with the equipment supplier.

Low-emission Logistics

Low-emission logistics in these projects do not receive much attention. Although some stakeholders do mention low-emission logistics solutions, they are not implemented in the projects. The stakeholders are aware of the benefits some design choices like modularization and material optimization have on the emission from logistics. Municipality B and D explain that they stimulate developers and contractors to work with electrified logistics and transport over water, but leave it to their own initiative (Municipality B, Municipality D).

Developer A and Contractor B explain that they will start using low-emission HVO fuel from next year on to reduce carbon emissions from logistics and equipment (Developer A , Contractor B). Developer B thinks it might be the next step, but is focused on reducing emissions from concrete production first.

> *'You cannot get around your transport. That will always result in nitrogen and particulate matter emission. It could be the next step to transition to electrified transport, but that will take some time." (Developer B)*

Low-emission end-of-life management

This low-emission practice was not applicable to the cases and is partly implemented into low-emission design and low-emission construction practices since the optimal form of reuse and recycling is reusing the structure that is already there.

Barriers

Table 17 shows the barriers that were perceived by the participants in multiple cases or in a single case, but in line with the theory. Per type, the most notable barriers per type are explained.

Economical

A barrier that is mentioned in all four projects is that low-emission solutions can be costly and can therefore put the business case at risk. This applies to both material and equipment costs. According to some stakeholders, the 'pain' of the innovation is felt by all supply chain stakeholders due to investments in time and money in innovation. The low margins in construction, which make this barrier a serious threat to the implementation, is mentioned by stakeholders in multiple projects.

Political

In all projects some political barriers were mentioned, but on different levels of government. On the municipal level, projects B and C experience delays because of the lengthy permit procedure process, because of their low-emission design solutions. In both cases, the contractor explains that it takes the municipality a lot of time to approve the safety of new construction techniques and that the departments of the municipality to handle these permit applications have no incentive to speed up their process.

Developer B and Contractor C both explain that lack of ambition from the start and hesitation at the municipality can be a barrier for the market parties. Another political barrier mentioned in many of the projects is that the MPG calculation method not an adequate tool to realize low-emission projects, since many good solutions will not receive credits.

Institutional

The first institutional barrier that is mentioned by participants across the different projects is the position of low-emission criteria in relation to other selection criteria in decision-making processes by several stakeholders, like developers and investors.

> *'As a developer you must comply with many rules and regulations. This makes real estate development a complicated profession. Sustainability is added to that list of requirements and for me this comes on the first place, but many others think it is just another requirement' (Developer A)*

Lack of ambitions, unclear ambitions and or too many ambitions are also mentioned as important organizational/institutional barriers.

> *'For this project we have decided, and we need that as contractor, to focus on one area, since sustainability is a container definition' (Contractor C)*

Technological

Many of the barriers in the case studies are technological, since supply chain actors are not used to working with low-emission martials and equipment and because the market for low-emission materials and equipment is still underdeveloped. The shortage of materials, shortage of suppliers and unfamiliarity with technologically innovative practices are classified as technological barriers and are encountered in all four projects.

Barrier	Type
Too small margins in developments too implement sustainability	Economical
Economical | Investments in new equipment are significant	Economical
'Financial pain' of innovation felt in whole chain	Economical
Low emission materials often more expensive than traditional	Economical
Capacity design team maximum ambitions	Institutional
Developers / investors steer on return instead of wider values	Institutional
Investors with traditional and inflexible requirements for their assets	Institutional
Stacking of ambitions	Institutional
Suppliers do not necessarily have design skills	Institutional
Lack of time and flexibility	Institutional
Environmental criteria in decision-making inferior to other criteria	Institutional
Unclear definition of sustainability	Institutional
Unclear or lack ambitions from start	Institutional
MPG calculation incomplete/black box	Political
Municipality will not demand above-the-law regulations	Political
Multiple 'hats' municipality.	Political
No public incentive for low-emission practices	Political
Water risk during timber construction	Technological
Electrified trucks cannot drive long distances	Technological
Not enough knowledge on new technique	Technological
Shortage of electrified equipment	Technological
Height limiting factor for bio-based construction	Technological
complex buildings with many functions easier in concrete	Technological
Shortage of (local)suppliers	Technological
Net congestion can limit electrification of construction-sites	Technological
level of detail needed before construction starts	Technological

Table 17, Perceived barriers from different cases

Drivers

Table 18 shows the drivers that were perceived by the participants in multiple cases or in a single case, but in line with the theory. Per type the most notable drivers per type are explained.

Institutional

More than half of the quotations for low-emission practice drivers are institutional or organizational. Several stakeholders refer to the importance of others' stakeholder's mindsets and ambitions as one of the most important drivers.

" I don't know exactly how to arrange it organizationally, but I think it is mostly in the drive of people and their feelings. We really need to want to do things differently and if we all have the willingness, a lot can happen." (Developer A)

Developer B explains that it is important to involve a contractor in the project that has the courage to step into an innovative project (Developer B). Contractor C explains that they are motivated by their intrinsic motivation to limit emissions. They have formulated low-emission ambition for themselves, not only to reduce the impact on the environment but also to improve their own working conditions (Contractor C). In Project D both the contractor, supplier and the municipality refer to the mindset and ambition of the architect and client as the main driver behind the emission-reduction in the process (Contractor D, Supplier D, Municipality D, Clients delegate D).

A few interviewees explained the importance of formulating ambitions and the timing of formulating them. Contractor A explains that the contractor, developer and architect should formulate the ambition as a carbon ceiling in the beginning (Contractor A). Architect A explains that a client/developer who raises the bar can work really stimulating for them to make a difference and investigate possibilities to meet their ambitions (Architect A). Contractor C agrees with the above, while this wasn't the case in project C, by saying the following.

'I think that, with the knowledge we have right now, the developer in the initialization- and design phase could have committed more to developing a sustainable building (Contractor C).

The selection of CLT and other biobased materials was driven by the ambition to meet the criteria for the BREEAM certificate according to supplier D. This is also an ambition that was set from the start by the client and the architect together (Municipality D).

One of the drivers that was mentioned in projects B and D, where innovative construction techniques were planned early in the process, the configuration of the design team was seen as a driver. The early involvement of suppliers was seen by some stakeholders as essential to the design process (Developer B, Supplier D).

Economical

In projects A and C the selection of the circular façade tiles and stone strips was cost-driven, more than it was emission-driven (Contractor A, Developer A). In project A, it was an innovative façade system, that offered an affordable solution for their design. In Project C the stones are cut into slices by the contractor to reduce the material costs. Not only in the façade but in the foundation as well, the material reduction can lead to a cost reduction for the contractor and this can lead to an emission reduction as well (Subcontractor C).

Political

In project A, developer A mentions that the collaboration with the municipality was one of the important drivers in this project:

> *' What is really crucial, is that the municipality had a project organization with a dedicated project manager. One who was instructed to think along with the developer, how to make the project feasible. There were legal agreements, but there was also willingness to think along.'* (Developer A).

In project B, the project organization and -manager from the municipality were also quite collaborative and this has resulted in renegotiations on the land sale price and an attempt to streamline the permit procedures (Municipality B). In Project C no political drivers on the municipal level were mentioned by the interviewees. In Project D, trust and collaboration between the municipality and the client was a driver behind the ambitions of the project according to the municipality (Municipality D).

Technological

Technological drivers for the implementation of low-emission practices were mentioned in project C, but not in the other projects. The optimization software used by the subcontractor is one of the technological drivers and the other is the live measuring of electricity usage, which has made it possible to only connect to a small connection to the grid (Subcontractor C, Contractor C).

Driver	Type
Sometimes less material can lead to cost reduction	Economical
Create financial incentives for organization to optimize the plan	Economical
Stakeholders' prior experience/knowledge in the innovation	Institutional
Clear ambition set from initiative (certificate)	Institutional
Close collaboration with the architect, contractor and relevant suppliers and consultants.	Institutional
Early involvement of expertise; supplier, contractor	Institutional
Ask the right question to (sub)contractors and suppliers	Institutional
Add low emission criteria in procurement	Institutional
Stakeholders' mindset and intrinsic motivation	Institutional
Specialized consultant for BREEAM certificate	Institutional
Subsidies for higher score on certificate	Institutional
Flexibility in the team	Institutional
Dedicated project manager	Political
Regulations on maximum emissions from governments	Political
Lower land price	Political
Earn points in municipal design competition and keep parties to it	Political
Dedicated project manager in close contact with permit department	Political
Flexibility and trust between developer and municipality to negotiate	Political
New technologies allow for material optimization/reduction	Technological
Live measuring of electricity usage	Technological

Table 18, Drivers from different cases

Typical to Dutch inner-city high-rise projects

While many findings on the implementation of low-emission practices are also applicable to low-rise projects outside the existing fabric, some participants mentioned specific challenges to the inner-city

high-rise context. Project C has some characteristics that are typical for inner-city developments. The floorplan has an odd triangular shape and the building hosts multiple functions. The developer explains how this effects the material selection for the construction:

> *'When you built an complicated building, steel and concrete construction is preferable, because it offers a lot of possibilities. If not everything is right on top of each other and the building has large spans, you know for sure that it's going to be a problem when you do not use concrete. For fire spread regulations as well" (Developer C)*

In project D some parts of the building are constructed in concrete and steel instead of wooden modules, because of the complex shape of the floorplan (Contractor D). In project B the construction is not entirely made off timber. Some steel and concrete is added for stabilization, because of the height of the building (Developer B)

Role of the project developer

In all four projects the developer has involved the contractor and sometimes more relevant stakeholders early in the design team and this is seen as something that supports the implementation of low-emission practices.

In project B and D the ambition of the developer (and the architect) is seen as a driving force behind the implementation of low-emission practices. In project D the developer has taken full control over all phases in the process and this was also the most ambitious project in terms of emission reduction.

However, since the developer seems to be an important stakeholder to set the ambitions from the start. The other stakeholders involved have to share the mindset and can even exceed the expectations of the developer when intrinsically motivated, like contractor C.

Part III Synthesis & validation

In this chapter the main take aways from the case-study research will be tested in the validation session. After the validation session the low-emission steering model for developers will be designed

Validation of results with an expert panel

After comparing the results from case-study research with findings in theoretical research some preliminary conclusions were established. Since this research is based on four specific cases and the conclusions to be drawn are meant to support developers and other supply chain actors in the entire Netherlands, the results need to be validated before a generalization can be made. For this validation, an expert panel of four was selected based on the following criteria:

- At least one project developer is part of the expert panel.
- At least one contractor is part of the expert panel.
- At least 5 years of experience in construction.
- Personally worked in design teams.

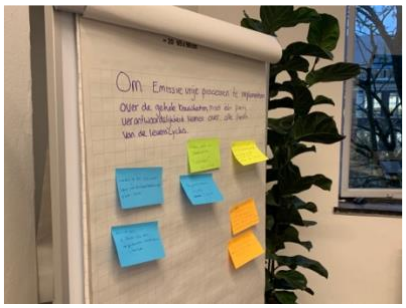
Eventually, the expert panel consisted of one real estate developer, one cost-expert from a real estate developer, one contractor and an architect.

Name	Type of organization
Participant A	Developer
Participant B	Developer
Participant C	Architect
Participant D	Sustainable concepts collective of contractors

Table 19, Participants in expert panel

The panel was briefly informed about the research topic beforehand and a short presentation with a summary of the research process. The participants were not given too much info to prevent them of being influenced by the results. At the end of the presentation, two statements and one question were shown to the panel. Every panel member received 15 minutes to write their first thoughts about the statements and questions on their own color Post-it note. After the individual session, the members were asked to explain their statements and respond to each other. The conclusions of the plenary discussions are described below.





Photos 1, 2 & 3 of validation session (Own photo, 2023)

<u>Statement 1: The Dutch construction industry does not need the government to implement ambitious emission-free practices.</u>

The participants collectively disagreed with the statement. Although they do agree that the government should not have to 'carry' the ambitions a supportive and facilitating role is important. The discussion that followed had two important outputs.

Firstly, the national government can play an important role by implementing norms and regulations and the municipality can set ambitions for an area instead of an individual plot (Participants A, C &D). These norms and regulations must be in line with European ambitions since most participants agree that the current MPG calculations are not stable and can lead to different outcomes for identical plans (Participants A & B).

Secondly, public bodies can organize low-emission logistics better than market parties, since they can link construction logistics to other sectors, which can make material hubs into a financially attractive business model. The government can step across borders, where some market parties can't. Some participants argue that the emission impact of construction logistics is marginal, but that of logistics of a whole is more significant and that it should therefore be treated as a whole.

Statement 2: To implement emission-free practices across the supply chain one party should take responsibility for all life-cycle stages.

Parties agree that it would be difficult for one party to take full responsibility in all stages. One party would not have all the expertise, so the full potential wouldn't be used. The municipality should set the first ambitions and afterwards, parties should take responsibility in the step in the construction process where their strength lays. If parties work together and speak the same language, ambitions will be more likely to be achieved.

The participants explain that a low-emission process cannot yet be quantified as a financial asset to a building. An example is the material passport. Partners during construction need to invest in such a passport but will not get a financial return on their investment. If environmental performance of the construction process of a building or the reusability can be financially attractive for the owner and traded together with the building it would become an interesting investment.

In the case of low-emission logistics, if there is not one party in the supply chain that can take on the responsibility of low-emission logistics, perhaps the municipality should take control over an area development and charge vehicles for entering the area and offer material hubs at the vicinity of the area. The parties agree that this could be a solution, but it is far from the current reality.

Question 1: How can a developer set ambitions for all parties in the supply chain, without transferring risk from them to the developer?

The participants are not completely sure whether the developer should be the one to set the ambitions for other parties. Ambitions should be set as a team and some departments at the municipality are essential in this process as well. The ambitions are not all to be set by the developer. The municipality has an important role in this process.

It is always important to translate ambitions into contracts and steering needs to happen top-down in a construction project. BREEAM and BENG2.0 are mentioned as possible demands. The participants explain that the one who demands it has to take financial responsibility as well. The parties should review the possibilities to reach the demands together. If the project is not feasible, the parties can take a step back. It is easier to lower the ambitions during the development process than to raise the ambitions during the process.

Taka away for framework:

- According to the panel, there is an important role for the government in low-emission construction by setting rules and regulations and by coordinating logistics on area or city scale.
- The participants think that responsibility for low-emission practice implementation across the supply chain cannot lay with one party and should be shared according to expertise. And in close collaboration with the municipality.
- If the developer does take responsibility, they agree that ambitions should be set as a team and certificates, or calculation methods should be linked to it. Stepping back is easier than raising ambitions at a later moment.

Design of the Low-Emission steering framework for developers

The combination of theoretical and empirical research has provided information on the implementation of low-emission practices by different stakeholders, the experienced barriers and drivers and the position of the developer in these projects. The framework in Figure 15, contains four low-emission core practices and their interrelations on the top since it is important for all stakeholders to be aware of interrelations and implications of decision-making in different stages. End-of-life management was not included, since the cases did not provide input for this and since empirical findings show that material selection and also reusing existing materials is more of a design choice than a different category.

On the vertical axis, the most important stakeholders are positioned and where core practices and stakeholders cross, actions for real estate developers to promote the implementation of low-emission practices are mentioned. The developer needs to guard ambitions over the whole process, bit the execution and responsibility shifts towards the executing parties as can be seen in the framework. A further explanation of the separate action can be found next to the matching numbers in Figure 16.

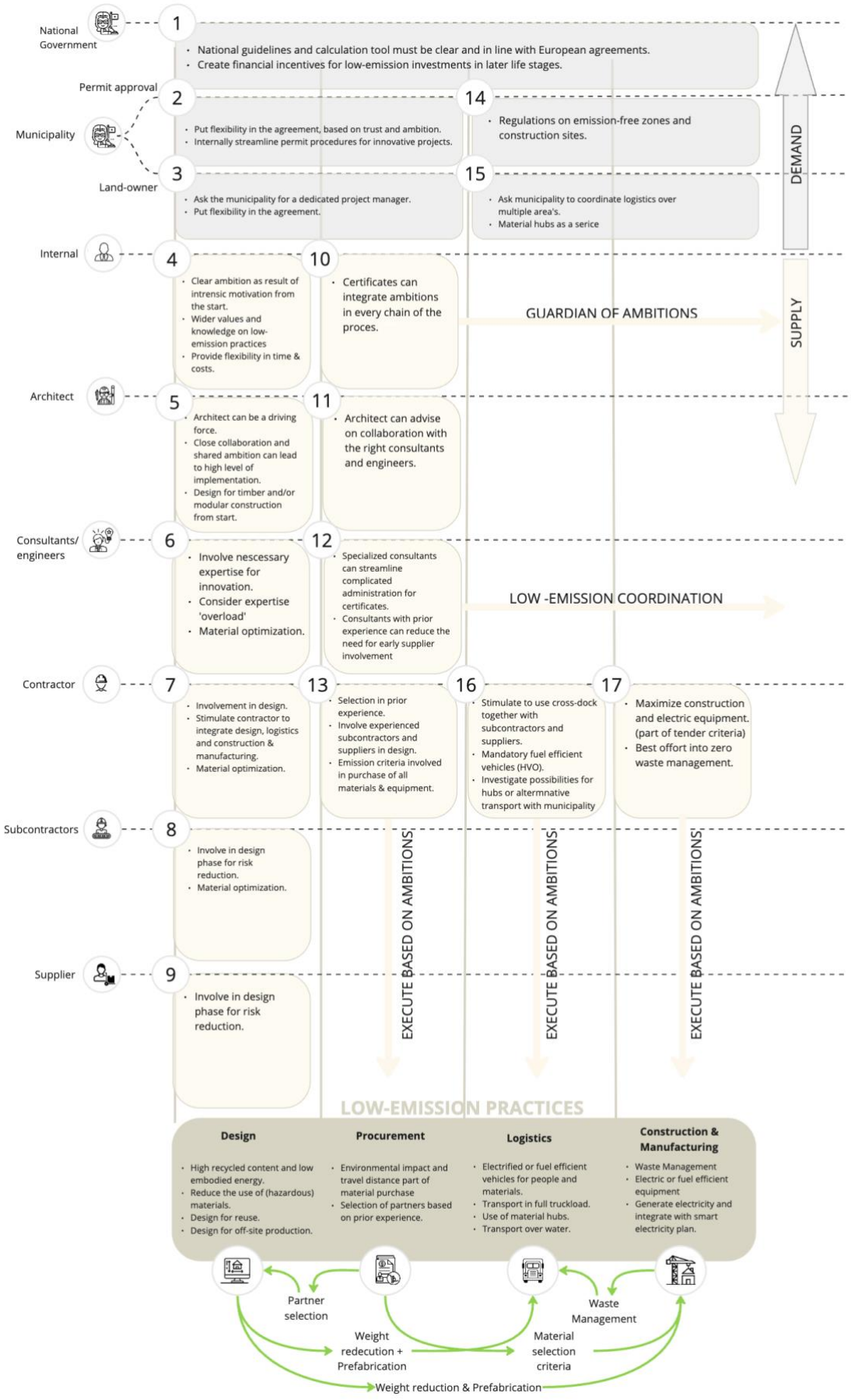


Figure 15, A conceptual low-emission steering framework for developers (own work)

Figure 16, Explanation to the conceptual low-emission steering framework for developers (own work)

5 Discussion.

Chapter 5 | Discussion

In this discussion, the findings from theory and the data from the empirical research will be compared to each other. Noticeable differences will be highlighted and explained as well as possible. First, the different low-emission practices and the roles of the most important stakeholders in implementing these practices will be discussed. Then the similarities and differences between barriers and drivers from theory and practice in implementing these practices will be discussed. Finally, the influence of the research context and the quality of the research design will be determined to establish the validity and generalizability.

Theory versus Practice

To build a theory around the practical implementation of clean- and emission-free processes for Dutch high-rise construction the dynamics of the construction industry are important to map at first. Three important characteristics of construction projects, a unique location, a one-of-a-kind product and the resulting temporary project coalition, make it difficult to innovate in the construction sector (Vrijhoef & Koskela, 2005). The organization of the temporary project coalition is the topic that addressed in this thesis, since this is one of the major barriers to greening the supply chain (Badi & Murtagh, 2019).

The organization of a low-emission supply chain and the roles of different supply chain stakeholders in it is not defined in academic literature yet. However, green supply chain management is gaining popularity and the green practices; design, procurement, logistics and construction and manufacturing from Balasubramanian et al. provide insight in de stakeholder roles, barriers and drivers in limiting the environmental impact from the product until the end-of-life stage of a building (Balasubramanian & Shukla, 2017a; Nwodo & Anumba, 2019) On this foundation a theory was built on the roles different stakeholders should have in a low-emission supply chain and if and how the developer could integrate the supply chain.

Based on the core low-emission practices and the most important stakeholders in the supply chain, case study projects were selected that could offer insight in the execution of some of these practices by stakeholder in the Dutch inner-city context. Similarities and differences between the theory and practice are described below.

Low-emission design

According to Balasubramanian and Shukla the role of the contractor, subcontractors and suppliers in design is minimal and all impact is with the municipality, developer and architect in this phase (2017b). According to Ferme et al. contractors and suppliers should be involved early on because changes on materialization can still be made by then (2018). In the case study projects the contractor has an important role. In all four projects, the contractor is involved in the design process just like relevant suppliers like timber suppliers. This maximizes the utilization of the knowledge of the contractor, which is useful in innovative projects (Holloway & Parrish, 2015)

In literature architects and consultants are seen as executors of developers' demands, but in projects B and D the architect was in close collaborating and proved to be a driving force according to multiple stakeholders (Balasubramanian & Shukla, 2017a) Developers demands and ambitions however are very important factor. Another interesting point is that many stakeholders see optimization of concrete

compound and other concrete construction techniques as a more realistic carbon emission reduction measure than timber construction. The idea to create an emission budget that can be monitored during the design phase, which was raised by Developer B and mentioned in the validation session, could be useful to make informed decisions in the design phase.

Green procurement

Green procurement is divided into the procurement of services and the purchase of materials. In theory, the purchasing of materials is generally done by contractors. On top of that contractors often hire and/or select subcontractors and materials suppliers. Developers are not involved in material purchases in most projects, but involve architects, consultants and a contractor to the project (Balasubramanian & Shukla, 2017a).

In the empirical research the purchase of the right services or the selection of the right partners by the developer is often mentioned as an important driver behind environmental- and project performance. The separation between the contractor and the developer in procurement is not as strict in practice as mentioned above, but more in line with the partner structure discussed on page 34 (Ozorhon et al. 2014). Together with the architect and contractor the developer selects the right subcontractors and suppliers. Some suppliers like the timber supplier in project B and the timber module supplier in project D are involved in the design process. The developers were in this case actively involved in the selection of suppliers and materials. In case D, in which the use of biobased materials is maximized throughout the design, the client has taken control over every aspect including the selection of materials, which could be a sign that full integration and coordination by the developer has appositive effect on the implementation.

Procurement can be used as a tool for the avoidance of the use of hazardous materials and equipment and the main barrier in doing so is the strong focus on price (Adetunji et al., 2008) In project C environmental selection criteria were considered in the selection of the façade material, but stakeholders agree that cost were main reason for selecting the sustainable stone. In Project D the BREEAM certificate was a very effective way to streamline the procurement of materials and services across the full supply chain. The empirical results in this case confirm the theoretical findings. However, it must be noted that multiple stakeholders admitted that reaching the BREEAM increased development costs significantly.

Green logistics

In theory logistics emissions can be limited through minimizing material and employer travel (Setyaning et al., 2020). Distance of the materials to the construction site, the weight of the materials and the mode of transport are factors that influence the amount of emissions that result from logistics (Zhang et al., 2013). Interviewees acknowledge this in the exploratory and the in-depth interviews but low-emission logistics practices are not implemented in the case study projects. According to Fufa et al. Architects and developers can influence logistics emissions through design and material selection (2019). The projects all have examples of design choices where the use of materials is minimized, which leads to a reduction of transport as well, although this is not seen as a goal.

In the validation session, limiting logistics emissions is seen as something that the industry cannot achieve on its own, but is something that needs to be achieved in collaboration with other sectors led

by the government. This confirms the vision of the multi-actor model by Fredriksson & Huge-Brodin, in which low-emission logistics is seen as a concept with multiple scale levels and three important groups of actors: developer, contractor sand municipalities (2022). According to this article responsibility for clean construction logistics should be with the municipality, since decisions on land-use restrict what plans can be made by developers and plans of developers restrict the logistics by contracting parties. Clients should therefore demand a change in modal split and energy efficiency of their contractors based on land agreements with the municipality (Fredriksson & Huge-Brodin, 2022). Developers and contractors are ready to act within the boundaries currently available technologies provide, since some of the participants already plan on demanding low-emission fuel in within the next few months. However, none of the municipalities in the case study projects have included it in the requirements.

Green construction & manufacturing

According to Zhang et al. construction emissions can be minimized by using environmentally friendly materials, waste management and prefabrication (2011). In this thesis, material selection is seen as a design choice and therefore discussed in the design paragraph above. Most relevant are the energy usage on-site, whether this is electrified or diesel-driven, and the amount of waste production and where this must be transported to (Zhang et al., 2013). According to Balasubramanian & Shukla, energy use on-site, electrification and waste management is something that developers, architects and consultants are not involved in. Contractors and suppliers do implement low-emission construction practices (2017a). As discussed in the cross-case analysis, contractors take the lead without pressure from municipalities and developers in implementing low-emission practices on-site. Municipal demands do not reach further than protecting Natura 2000 areas, and developers and designers are more interested in bringing down carbon emissions from material production since they feel that they can have more impact there. Many participants explain that not all vehicles and equipment can be replaced by electric types since the market for electric vehicles is not mature yet and investments are big. From an industry perspective it is understandable that not all equipment can be electrified, but developers can select a contractor that is intrinsically motivated to do so, since project C has shown that some can organize a low-emission construction site.

Barriers

The barriers found in empirical research do not differ that much from the barriers in theoretical research. An important type of barrier in empirical research is of the technological type. Currently available electric equipment is still underdeveloped, and low-emission materials are technologically and practically less favorable than traditional materials like steel and concrete. One of the other barriers that is mentioned in both the literature and in the interviews is the high costs of implementation of both low-emission materials as electric equipment. Since margins can sometimes be small in construction projects, this leaves little space for innovation, which low-emission construction still is. These barriers are difficult to solve by the project stakeholders. This existence of these barriers is confirmed in theory (Balasubramanian & Shukla, 2017a; Munaro & Tavares, 2023).

The empirical findings showed two important political barriers typical for the Dutch context. Firstly, the permit procedures for innovative construction system can cause significant delays. Secondly, the Dutch ‘MPG’ environmental performance calculation guidelines are not clear and do not match European guidelines and upcoming national emission ceilings. These did not come across in literature, but were confirmed in the validation session.

In literature many barriers that are related to the quality and willingness of project stakeholders are discussed (Balasubramanian & Shukla, 2017a; Darko & Chan, 2017; Munaro & Tavares, 2023). As can be seen in the cross-case analysis barriers related to the formulation of ambitions, capacity of stakeholders and stakeholder awareness and are mentioned in the case study projects as possible barriers as well. Although it must be said that most participants were satisfied with the project, they were more critical on external barriers than their internal process. This is possibly one of the reasons why many of the drivers are institutional. An important barrier mentioned by multiple stakeholders is the maximum capacity that stakeholders have in combination with the stacking of ambitions by municipalities and developers. Innovating will cost time from multiple stakeholders, so decisions have to be made and next to environmental criteria, developers and other industry stakeholders are expected to meet social and financial criteria as well.

Drivers

What stands out from the cross-case analysis is the focus on institutional drivers over political and technological as research would suggest (Munaro & Tavares, 2023). The empirical results show a strong focus on collaboration between intrinsically motivated stakeholders, prior experience, timely involvement of expertise and setting the right and measurable ambitions. In theory low-emission construction is mostly driven by political incentives and regulations, but these were not mentioned as important barriers by the case study participants. However, the validation session provided interesting insight, since participants in this session were focused on the political barriers and drivers more than institutional ones. An explanation for this difference could be that there was a lack of political incentives and regulations in the case study projects, which resulted in a greater responsibility for the private organizations to set ambitions and standards. The current case studies offered an insight and provided lessons for the drivers in a context with a lack of political involvement. When the participants in the validation session were asked to look ahead, they favor a future in which the responsibility of meeting environmental demands shifts towards the government. This will create a level playing field and force all construction organization to meet the same requirements. The attitude of stakeholders in de validation session is more in line with theoretical findings than the results from case study research (Munaro & Tavares, 2023).

Quality of research design

To discuss the quality of the research, design the validity of this thesis and the research method is assessed based on the three ‘tests’ in the bullets below:

- Construct Validity
- External Validity
- Reliability

Construct Validity

Construct validity concerns whether the observations the researcher does and the relations that the researcher notice actually say something about the event to be studied or are influenced by the own perception of the researcher (Yin, 2018). To improve the construct validity multiple sources of evidence have been used; five exploratory Interviews, eighteen in-depth interviews with stakeholders from four

different construction projects and an expert panel discussion. The expert panel was used to test the first conclusions drawn based on the case study results, which is also beneficial for the construct validity (Yin, 2018)

External Validity

External validity concerns the extent to which the results of a study can be applied to other settings or populations beyond the ones that were studied (Yin, 2018). Unlike in survey research, case study research results cannot be generalized statistically. Case study results are generalized analytically by the best abilities of the researcher (Yin, 2018). This research is focused on inner-city developments of 30 meters and higher in the Netherlands. Within these boundaries, the results and conclusions would be generalizable and can be useful for construction stakeholders to use. Since the political context plays an important role in construction, four different municipalities were selected for the case study objects to eliminate the political factor. However, it must be mentioned that all four projects were just completed or near completion, which means the projects have roughly taken place during the same period. The economic context and political regulations or climate can change in time and have a significant effect on stakeholder behaviour. This means that barriers and drivers in low-emission construction can change quickly over time and different barriers and drivers can play a role in the initiation phase today compared to 7 years ago.

Reliability

The third and final test is about reliability or whether other researchers can repeat my protocols and get the same outcomes (Yin, 2018). Every step in the process of this thesis is carefully documented to improve reliability. The protocols of the exploratory interviews and in-depth interviews are part of the appendix and transcripts are available upon request. In chapter 5 the research methodology is explained and in chapter 6 the collection and analysis are described extensively for other researchers to imitate.

Limitations

Definition of low-emission construction

The definition of low-emission construction and the division into five core practices was developed based on a combination of green supply chain management literature, life-cycle assessment literature and literature on air emissions from construction. This has led to a definition with core low-emission practices and proposed roles for the most important construction actors that were not used outside this thesis before. In the interviews, it sometimes was hard to explain to participants which topics within their projects were relevant for this thesis and which were not, since it was not an established theory.

The variety of low-emission practices is also very big, which makes it difficult to determine the influence of one stakeholder, the developer, on the whole. Also, being able to draw conclusions on the role of different stakeholders on a topic as broad as low-emission construction challenging based on four cases only. Some low-emission practices were present and similarities between cases on those practices can provide valuable generalizable lessons. It is more difficult to draw conclusions on the roles of different stakeholders on low-emission logistics if very few, or just one, participants mention it.

Selection of case study projects and interviewees

A limitation of the selected cases is that none of them was still in the planning and design phase, but all projects were delivered or in the final phase of construction. It would have been interesting to collect information about the decision-making process in the first phases of the project, which the current knowledge stakeholders have. There were many stakeholders in the interviews who would have made different decisions looking back, since reducing construction emissions is only recently gaining attention across the industry. On the other hand, completed projects do provide an insight into the full process and practical implications decisions in the initiation phase can have. Therefore, completed projects were selected for this thesis, since the stakeholders have completed (most of) the work and overcome some of the obstacles of which other projects can learn.

6 Conclusion.

Chapter 6 | Conclusion

SQ1 | How can emissions related to the construction process for high-rise construction in Dutch cities be minimized throughout the supply chain?

Carbon, nitrogen, and particulate matter emissions can be emitted during the production and transportation of materials, logistics and fabrication activities on-site and during demolition activities. Projects stakeholders can affect the number of emissions in several stages of the development process. In this research five core low-emission practices are distinguished: design, procurement, logistics, construction & manufacturing, and end-of-life-management.

In low emission design the use of materials with a high environmental impact due to the production process or the distance to the project site should be minimized. For example, by using bio-based materials instead of concrete and steel. In high-rise construction, the use of steel and concrete is sometimes inevitable, so optimizing the amount of concrete needed and altering compound of the concrete to limit the amount of cement needed could be a solution as well. Reusing existing structures will always have an even lower environmental impact than building a low-emission new structure. The design of a building and the selection of certain materials effect the possibilities to reduce emissions during construction and logistics.

Low-emission procurement can be divided into the procurement of materials and services. It is important that low-emission or environmental criteria are both included in the selection of partners as the purchase of materials.

Low emission logistics can be achieved by using an optimal travel distance and modal split. On top of that the type of fuel or electric vehicle that is used has an impact. Off-site fabrication in a factory can reduce the movements from and to the site and possibly optimize the number of movements in general, but this is not the case by definition.

In Low-emission construction & manufacturing production on- and off-site should be executed with fuel-efficient or electric equipment as much as possible. Production in a controlled environment like a factory can reduce emissions, but doesn't do so by definition, so stakeholders should still be critical. In case of redevelopment of a site with existing structures, the most optimal form of low-emission end-of-life management is to reuse the existing structures. Reusing existing structures should always be considered.

SQ2 | What actors internal and external to the supply chain influence the implementation of low-emission methods for high-rise construction in Dutch cities?

The national government and municipality are the most important external stakeholders influencing the construction supply chain since the municipality can set demands for maximum level of emissions. The developer is the one who translates the market/political demand to an ambition for the rest of the supply chain. The developer will also involve the architects, necessary consultants, and the main contractor. For more complicated low-emission high-rise projects the project team could benefit from a specialized low-emission consultant to monitor emission ambitions. The low-emission consultant helps negotiate conflicting interests during the design and pre-construction phase. The main contractor will, together with the developer, invite subcontractor sand suppliers to the project. These parties

together are responsible for and can affect the number of emissions resulting from the construction of buildings. The developer and contractor have a leading role in this process. Apart from these internal stakeholders, investors and insurance companies can also influence the implementation of low-emission practices in the supply chain on the demand side. Selecting intrinsically motivated partners applies to all the above-mentioned disciplines since some organizations are significantly ahead compared to others.

SQ3 | How are low-emission practices currently implemented in Dutch high-rise construction projects and what is still missing?

In the case study projects most actors showed attention to low-emission design practices, but in two of the cases, an orchestrated approach was missing. When extra effort was put into low-emission procurement of services, the implementation of low-emission design practices profited as well. Only in one of the four projects the procurement of all materials and services was coordinated from the start by the developer and this resulted in a high level of implementation of low-emission practices throughout the process.

None of the core stakeholders feel responsibility for low-emission logistics. All of them encourage the use of different modes of transport and electrified transport, but none of the external and internal stakeholders enforce it. Municipalities, developers, architects, contractors, subcontractors and suppliers do see how design choices and construction techniques can limit the number of movements, but it is not seen as a goal in itself. Municipalities are in the position to coordinate low-emission inner-city logistics on a city scale. When facilities are in place, they can force developers and contractors to start using it.

Off-site fabrication of components and waste management are adopted by some core stakeholders to limit the environmental impact from on-site construction activities. The production of timber construction elements takes place in a factory and that results in a reduction of on-site activities and emissions. Pre-fabrication of concrete components is implemented widely, but stakeholders point out the negative effects this can have on carbon emissions. The use of electric equipment and the generation of electricity on-site is not coordinated by developers or municipalities outside Natura 2000 areas. Some contractors and subcontractors do focus on electrification, but this happens without pressure from other stakeholders. Developers feel that they would have to pay for an electric construction site, while this does not have to be the case for contractors who strive to lower emissions themselves.

SQ4 | What drives or withholds different actors to implement low-emission methods for high-rise construction in Dutch cities?

Important barriers in high-rise construction in Dutch cities are technological and financial. Because of the high level of innovation and an underdeveloped market, there is a lack of expertise on both public and private side. Materials and equipment for low-emission projects are generally more expensive than their traditional alternatives. Given the small margins in the construction sector, this makes it difficult to implement low-emission methods. Governments and municipalities can offer financial and legal drivers by offering incentives and imposing legislation. The absence of these incentives can even become a more important barrier for innovation. Current construction emission calculation method, the MPG, is seen as incomplete and a barrier for meeting European ambitions. Without public support,

private sector organizations can drive low-emission high-rise construction as well. Clear ambitions and a coalition of actors with the same ambition and mindset are the most important drivers in achieving low-emission ambitions.

SQ5 | What role can developers take in the implementation of low-emission practices for high-rise construction supply chains in Dutch cities?

Opinions of participants in the empirical research are divided on the role of the developer; some think their responsibility stops after design and others think the developer's influence should reach the end of the building's life cycle. From the five low-emission practices defined in this thesis, developers can in every project directly influence the design and procurement within a project. At the start of the project, the project developer should within the context given by the municipality, set clear ambitions for low-emission construction in the whole supply chain. Low-emission objectives need to be implemented in all service and material selection criteria. Selecting experienced architects, consultants, contractors, subcontractors, and suppliers is seen as one of the most important drivers in empirical research. These low-emission criteria need to include the full supply chain and not stop at material selection. During the design phase, the developer is the decision-maker and therefore the most important guardian of the implementation of low-emission practices in the design.

Developers should influence the low-emission implementation of subcontractors and suppliers legally through the main contractors. Since the control and expertise over the construction site and logistics are more with the contractor than the developer, these ambitions should also be part of their contractual agreement. It is important for a developer to integrate low-emission standards in agreements from the initiative of a project up until agreements with executing parties. This will be elaborated in the recommendation section.

Main research question: How can real estate developers organize a low-emission supply chain for high-rise construction in Dutch cities?

While theory and empirical research prove the interconnections between low-emission design, low-emission procurement, low-emission logistics, and low-emission construction & manufacturing, real estate developers are insufficiently aware of their impact and responsibility on the full supply chain. Empirical research shows that full integration and coordination of the supply chain by the developer will have a positive effect on the overall emission reductions in projects. but In the short term it is unlikely that the development sector voluntary will shift towards such an integrated system without a clear ambitions and enforcement from the public sector.

The strength and expertise of real estate developers to the benefit of low-emission construction of inner-city high-rise projects in the Netherlands can best be utilized in the procurement of services and in the design phase. Before procurement and design activities begin the developer should formulate clear low-emission ambitions which can be understood by stakeholders across the full supply chain and ideally are based on generally accepted frameworks or calculation methods. Procurement of services can be based on prior experience of organizations with executing the set ambitions, since sharing the same ambition and mindset between stakeholder organizations is one of the most important drivers in low-emission construction.

The architect and contractor are important in the coalition and in the procurement of services since architects with prior experience can involve relevant consultants and engineers who they have previously worked with before. Contractors in their turn are often responsible for the procurement of

services from subcontractors and suppliers. For innovative projects inner-city high-rise with low-emission materials, additional early involvement of expertise from suppliers and subcontractors can reduce the technological and financial risks that come with working with these innovative materials. The developer should be critical on the contribution of suppliers and consultants in the design team. Suppliers should not replace chief engineers and the main contractor could perhaps lower coordination fee, when a large part of the responsibility of the construction is transferred to a subcontractor or supplier down the supply chain.

During design, environmental optimizations and material selection can be stimulated by selecting and using a calculation method or certificate with the project team. This can streamline low-emission decision-making across the supply chain. It is beneficial to have a close collaboration and shared mindset with the architect, since this can result in a high level of integration in the whole design.

Low-emission logistics and construction & manufacturing is influenced by design and procurement as explained above. The selection of modes of transport, construction techniques and equipment can best be coordinated by the contractor since it is not within the expertise of a developer to manage a construction site. It is the responsibility of the developer to include low-emission demands in contracts and use this to influence the decision-making in the rest of the supply chain.

7 Recommendations.

Chapter 7 | Recommendations

The main recommendation for developers, but also for other market parties and government bodies to use, is the conceptual low-emission steering framework in the synthesis chapter. Additional recommendations to the market and possible leads for further academic research are described below.

For further academic research

Firstly, for the case study research four construction projects of 30 meters or higher in Dutch inner-cities were selected. The results and conclusions in this thesis are applicable to the Dutch context, so it would be interesting to do research in a different country or into different project types since this could lead to other context-specific barriers and drivers.

A second topic for future research could be to dive deeper into the ideal procurement practices for real estate developers in low-emission projects. In this thesis, the construction supply chain and the most important actors and relevant steps for realizing low-emission projects are discussed. It would be useful to zoom in on the tools and possibilities a developer can enforce low-emission behaviour through procurement. In this thesis, this was just one of the low-emission practices, but since the developer is most influential in this phase it could be interesting to investigate the exact procurement strategy and what type of clauses the developer should include in contracts with all stakeholders.

One of the outcomes in this research is that the government should play a more important role in setting ambitions, regulations and offering incentives for private parties to change towards low-emission construction practices. It would be helpful for governmental organizations to gain insight into the instruments they can use best to speed up the transition. The outcomes will probably differ depending on the level of government, since national regulations can help to change the rule of the game, but local authorities can coordinate construction logistics on area level for example.

Lastly, one of the results of this thesis is to use a shared calculation tool that exceeds the currently obligatory MPG and BENG guidelines. It would be interesting to do research into the use of such a calculation tool between different stakeholders. Some stakeholders criticized the current national systems and vouched for the use of a carbon calculation method, but companies who do calculate their emissions, use different methods and it is unclear which stakeholder within or outside the project coalition should be responsible for this aspect of the process.

For practitioners

It can be concluded that the government, developers, and contractors have an important effect on the implementation of low emission practices across the supply chain. Since none of these stakeholders will hold full responsibility over the execution in all phases, the question remains how these parties can assure that their ambitions will be realized by the other organizations involved. Five standard agreements in different stages of an average construction project can be used to translate ambitions into actions for the different stakeholders.

For public bodies

On a national level the government should revise the current MPG and BENG calculation methods and use a methodology that is in line with European targets for reaching net zero in building in 2050. Of course, the government on all levels should take on a front-runner position in their own construction

projects and implement strict low-emission criteria in service and material procurement. This can drive the development of new low-emission materials and the development of eclectic equipment.

When the municipality is owner of the land, at the start of the construction process the municipality and the developer should express their ambitions for the development in the letter Of intent. This is non-binding, but it is important the parties involved have a shared mindset and a clear ambition. This letter of intent precedes the purchase of land for which a Purchase and Sell Agreement (PSA) should be signed. In this agreement, the low-emission ambitions need to be specified further. This agreement should be used by the municipality to demand higher emission standards than currently required by national MPG and BENG requirements. Using a calculation tool, like some of the tools mentioned in the introduction or BREEAM, is advised. In this stage, a score can be given, but the way in which this score will be obtained in different steps in the supply chain is still open. Since the cost of innovation is still one of the most important barriers, the municipality should keep in mind that the level of ambition on emission reduction will affect the level of ambition possible on other aspects like appearance, social program, and land sale price.

As discussed in the conclusion low-emission logistics and the use of hubs is something that can better be organized on a higher municipal level. In the development agreement, the municipality and developer can discuss how the emission targets can be achieved and what responsibilities both parties have. Developers should bear responsibility for the implementation of LEP in design and the execution of LEP by the contractors and subcontractors; what modal split can be used for this location to limit logistics emissions? Will all equipment be electrified on the construction site or will the goal be to use as many prefabricated elements as possible? Municipalities should, in turn, offer the necessary facilities like material hubs and charging stations to meet their low-emission logistics ambitions.

For developers

As mentioned before project developers can have a significant effect on the reduction of construction emissions in the design phase and through procurement. The promised emission reduction towards the municipality needs to be realized by the private parties and therefore the developer should make sure that these are included legally in the agreements between involved parties.

It is advised for developers to, within the current market maturity, engage in a design team with the contractor, architect, and relevant advisors, since low-emission high-rise construction is still very challenging and involvement of the contractor in the design phase can reduce risk. In this agreement, the low-emission construction practices cannot yet be defined, since solutions need to be found in collaboration with the design team partners. However, the goals need to be clear and measurable. A clear goal linked to a shared calculation method, like BREEAM or another credit/calculation system, should be part of this agreement.

Just like there is a financial budget for the project, an emission budget should be agreed upon upfront. During the design process, the effect design choices have on the emission budget should be monitored just like the financial budget. It is advised to involve an experienced advisor to guide this process when the architect or contractor do not have this capacity. Based on the ambitions for the project, relevant subcontractors and suppliers can already be involved. For example, a timber supplier or a 3D module supplier. In the design team, all stakeholders have their own responsibilities. It should be the responsibility of the contractor to include logistics planning in the design phase to improve the chances of low-emission logistics and electrification of processes.

After the design phase, the developer will award the contracting agreement to a contractor, often the design team contractor. In this agreement, the low-emission practices need to be specified and monitoring of the implementation needs to be in place. Low-emission construction practices for materialization will be implemented in the design, but logistics, energy usage on-site and waste management needs to be included as a clause. Part of this clause should be that the contractor will execute construction according to the design. The contractor is responsible that subcontractors and suppliers will execute the work according to the low-emission practices agreed upon by the design team. The contractor will be responsible for reducing on-site emissions by electrification and, if possible, on-site green electricity generation. The contractor is responsible for low-emission logistics to the site and needs to select suppliers that use electrified vehicles or low-emission fuel. In return, the developer can offer financial incentives when emission goals are achieved.

As can be seen in figure 17, in agreements between the most important stakeholders the definition of low-emission construction is limited to a maximum number of emissions and a shared calculation session. It is not up to the developer to prescribe certain construction techniques upfront. The project developer will translate the ambitions to demands for the design team and gather the right expertise to execute the design assignment. Only in the construction agreement, low-emission practices will be specified in a more elaborated emission clause.

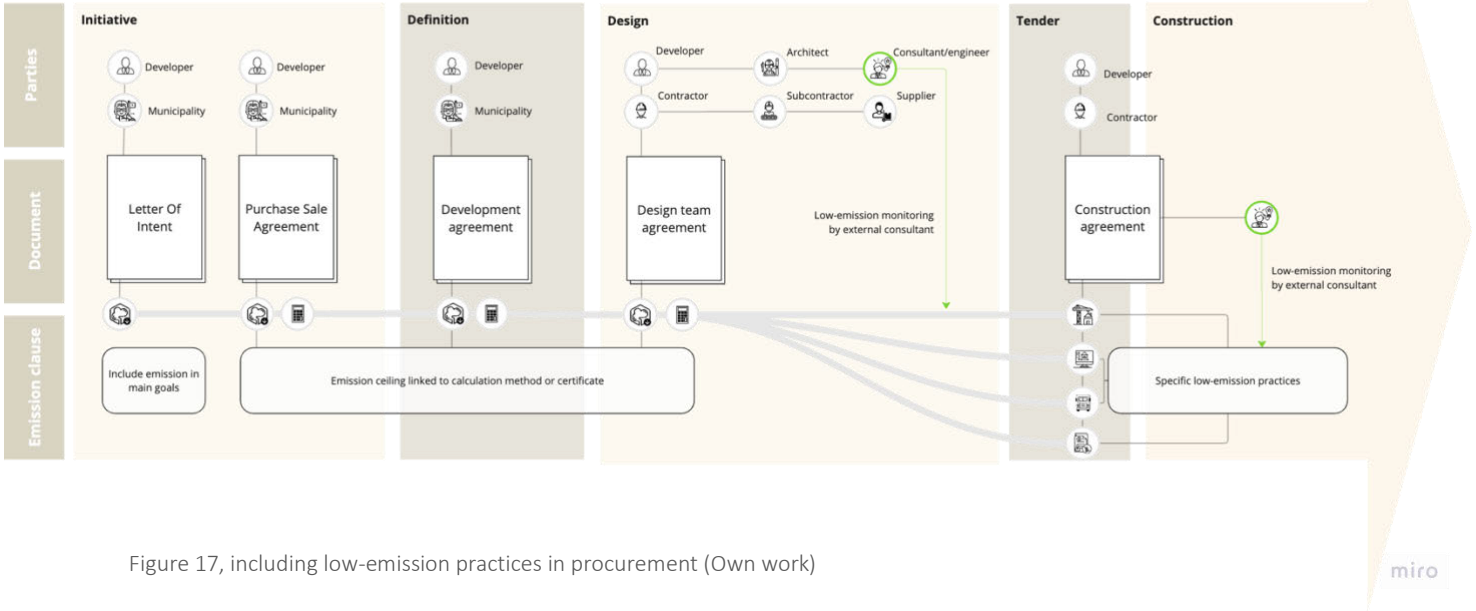


Figure 17, including low-emission practices in procurement (Own work)

8 Reflection.

Chapter 8 | Reflection

Topic

What interested me as Management in the Built Environment student was the complexity of the problem in multiple dimensions. First, the research is initiated by the four big municipalities in the Netherlands to, at the same time, fight global warming by reducing carbon emissions, limit environmental impact by nitrogen and particulate matter emissions regionally and locally and fight a national housing crisis. This already shows that the research relates to the global, national, regional, and local level. Secondly, while the research is initiated by the government, the execution of construction activities is carried out by market players in a scattered industry and with different values than public bodies. The relations between these stakeholders and the barriers and drivers in the collaboration that are related to the shift towards low-emission construction interested me and I think that is core to the design and construction domain of Management in the Built Environment.

The scope is relatively wide because there is a great variety of methods to lower emissions in the construction process and many stakeholders play an important role in implementation of these methods. Since this complexity is one of the major barriers of the greening of construction, I did not want to limit myself to just one low-emission solution or leave out other stakeholders besides the real estate developer. You cannot review the impact of the developer on the implementation of low-emission construction techniques without determining how the developer relates to other stakeholders in the supply chain.

It was difficult to define clean and emission-free construction and find literature on the effects different stakeholders have on the implementation of it and the barriers and drivers that relate to it. Some articles written on net zero carbon development, but this is primarily focused on the design process and not as many emissions in general. Building the concept of low-emission supply chain management based on the foundation of green supply chain management was an important step, since it related the stakeholder collaboration to emission reduction. The results have affected the recommendation, since the low-emission construction practices and the most important stakeholders were not defined without the theoretical and empirical findings therefore the framework gradually took form in the process, until the final weeks

Methodology

Previous studies on green supply chain management and the reduction of construction emissions concluded that further research on the topic should consider the collaboration between stakeholders in the full supply chain and come up with practical implications. I decided to do a multiple-case study to gather information from practice with the idea that this would lead to more practical outcomes. It was difficult to interview all relevant stakeholders in four supply chains for my master thesis. It was already quite challenging to find four projects that met the criteria, of which the core stakeholders wanted to meet up in time. I think that I have interviewed enough project participants to draw valuable conclusions since I feel that I have learned a lot about the stakeholder dynamics in relation to the implementation of low-emission construction practices. Also, similarities between the projects could be defined, which make the results more likely to be transferable.

A limitation of my chosen method is that it can only provide input about the methods applied in the case study projects and not all low-emission practices came across as much in every project. Looking back, it could have been useful to select industry stakeholders unrelated to specific construction projects but based on their knowledge of emission-free construction. However, if I had chosen that path their experiences could not be validated with those of other stakeholders within the same project. The

other benefit is that the selection of four projects helps to analyze the influence of decisions in different phases.

Academic and societal relevance

Academically this thesis contributes since it provides insight into drivers and barriers in stakeholder collaboration in relation to greening the supply chain. This is something that is mentioned as a gap in multiple literature reviews. On top of that stakeholder collaboration is strongly related to the context and previous research about green supply chain management or the reduction of construction related emissions in the Dutch context is scarce. This thesis now offers an insight in broad range of aspects related to the implementation of low-emission construction practices in construction. In terms of generalizability, I think it is good to realize that the four cases that were reviewed in this thesis are mixed-function, inner-city projects of 30 meters and higher and that for this type of location and project the results can be generalized. For one- or two-story housing-only developments outside the city center, many of the perceived barriers and drivers in this thesis will not apply. Of course, the country and sector is in development, which means that the context In which these type of developments take place can be very different in a few years' time. This will affect the stakeholder collaboration and therefore affect the transferability of the conclusions in this thesis as well.

The societal relevance is increased since it provides answers to a combination of topical challenges in the Netherlands. The urgency of the research problem is explained in the introduction and recommendations and this thesis provides practical guidelines to the initiators of building projects, which means that new developments can use the conceptual framework and the thesis as handle in the initiation phase. Public organization can use the results and conclusions to get a better understanding on the status quo and plan for a realistic pace of the transition together with the relevant stakeholders.

Process

Although you must execute the graduation process individually and I prefer working in teams, I have enjoyed the process. In the first place, I have met many interesting people across the industry through my graduation internship at Synchroon, workshops of the TU Delft research group, working at the AMS office and through the many interviews. This has given me a wide view on the sector and the people that work in it. My mentors from TU Delft, Ruben Stijn and Petar, and from Synchroon, Jochem and Maaike have helped me a lot in the process by providing feedback and asking critical questions. Ruben and Stijn have given me some useful advice on my methodology and scope. During P2 my research scope was very wide and did not have a real focus yet, so I decided to zoom in on the impact of the project developer. Something that was useful, since I could discuss about my findings internally at Synchroon, a project developer whose employees are eager to learn about sustainability and limiting their environmental impact.

At Synchroon, my tutors, could be critical at theoretical finding from a practical perspective, which helped my to prepare for the interviews, since I knew how market parties would think about some of the questions beforehand. All mentors were focused on the content and helping me to make progression at my own pace, which has given me energy during and after the meetings to move on. I have learned a lot about the development and construction process and understand that this transition will take a lot of effort for many different stakeholders. Therefore, it is extra important for construction stakeholders and governments to collaborate on this to develop future proof construction practices.

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Chapter 9 | References

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10 Appendix.

Chapter 10 | Appendix

Appendix I: Protocol exploratory interviews
Appendix II Protocol semi-structured in Depth Interviews
Appendix III: Validation session planning and reactions to statements
Appendix IV: Informed consent form
Appendix V: HREC Checklist
Appendix VI: Data Management Plan

Appendix I : Protocol Exploratory Interviews

Checklist Interview:

Before the interview:

- Send invitation and share consent form beforehand.
- Share date, time, and location.
- Arrange recording device.
- Control on informed consent and collect signed form

After the interview:

- Does the interviewee want to share something?
- Thanks for the input and check for validation of input and transcript

Questions:

1. Zou u uzelf kunnen voorstellen en uw positie binnen uw organisatie kunnen toelichten?

2. Hoeveel ervaring hebben u en uw organisatie met het beperken van emissies tijdens het bouwproces?

3. Sinds wanneer is dit aan de orde in uw organisatie?

Algemeen over aan het bouwproces gelinkte emissies:

4. Welke emissies kunnen er vrijkomen bij een bouwproces en in welke stappen is de uitstoot volgens u het grootst?

(Wanneer nodig aanvullen dat voor dit onderzoek naast CO2 ook stikstof en fijnstof wordt meegenomen en daarnaast toelichten in welke fasen deze stoffen vooral uitgestoten worden)

5. Welke ketenpartners of interne actoren denkt u dat in deze verschillende stappen de grootste invloed hebben op de hoeveelheid emissies?
    a. Kunt u een concreet voorbeeld geven van een situatie, waarin dit duidelijk naar voren kwam?

6. Welke rol spelen externe actoren, zoals de gemeente of andere overheden in deze verschillende stappen en welke invloed heeft dat op de hoeveelheid emissies?
    a. Kunt u een concreet voorbeeld geven van een situatie, waarin dit duidelijk naar voren kwam?

Mate waarin emissiebeperkende maatregelen al wel of nog niet zijn genomen (Deelvraag 3)

7. Welke maatregelen kunnen er in de ontwerpfase van dit project genomen om emissies over het volledige bouwproces te beperken?
    a. Heeft u voorbeelden?

b. Waarom lukt het in traditionele projecten misschien niet om deze maatregelen door te voeren?
c. Welke emissiebeperkende maatregelen zouden er volgens u nog extra genomen kunnen worden?

8. Welke maatregelen kunnen er in de aanbesteding genomen om emissies over het volledige bouwproces te beperken?
    a. Heeft u voorbeelden?
    b. Waarom lukt het in traditionele projecten misschien niet om deze maatregelen door te voeren?
    c. Welke emissiebeperkende maatregelen zouden er volgens u nog extra genomen kunnen worden?

9. Welke maatregelen zijn er ten behoeve van logistiek genomen om emissies over het volledige bouwproces te beperken?
    a. Heeft u voorbeelden?
    b. Waarom lukt het in traditionele projecten misschien niet om deze maatregelen door te voeren?
    c. Welke emissiebeperkende maatregelen zouden er volgens u nog extra genomen kunnen worden?

10. Welke maatregelen zijn er genomen om emissies uit de productie van bouwmaterialen te beperken?
    a. Heeft u voorbeelden?
    b. Waarom lukt het in traditionele projecten misschien niet om deze maatregelen door te voeren?
    c. Welke emissiebeperkende maatregelen zouden er volgens u nog extra genomen kunnen worden?

11. Denkt u dat het mogelijk was geweest om extra maatregelen te nemen in dit project? (Aanvullen tot BIMZEC en de vier Green Practices)

Appendix II Protocol semi-structured in Depth Interviews

Checklist Interview:

Before the interview:

- Send invitation and share consent form beforehand.
- Share date, time, and location.
- Arrange recording device.
- Control on informed consent and collect signed form

After the interview:

- Does the interviewee want to share something?
- Thanks for the input and check for validation of input and transcript

Questions:

This is an interview protocol for the semi-structured in-depth interviews with project developers within the case studies. The case studies all find themselves in a different context and in different stages of the project life cycle. For that reason, questions can differ between the interviews and interviewees are free to raise relevant topics that are not in this protocol.

1. Zou u uzelf kunnen voorstellen en uw positie binnen uw organisatie kunnen toelichten?

2. U bent betrokken bij project x vanuit organisatie x, kunt u iets vertellen over de positie van u en uw organisatie bij dit project?

3. Vanaf welke fase bent u betrokken bij project x?

4. In welke fase bevindt het project zich op dit moment?

Mate waarin emissiebeperkende maatregelen al wel of nog niet zijn genomen (Deelvraag 3)

5. Welke maatregelen zijn er in de ontwerpfase van dit project genomen om emissies over het volledige bouwproces te beperken?
    a. Waarom is het bij dit project gelukt om deze maatregelen door te voeren?
    b. Waarom lukt het in traditionele projecten misschien niet om deze maatregelen door te voeren?
    c. Welke emissiebeperkende maatregelen zijn er tijdens het ontwerp niet genomen?

6. Welke maatregelen zijn er in de aanbesteding genomen om emissies over het volledige bouwproces te beperken?
    a. Waarom is het bij dit project gelukt om deze maatregelen door te voeren?
    b. Waarom lukt het in traditionele projecten niet om deze maatregelen door te voeren?
    c. Welke emissiebeperkende maatregelen zijn er tijdens de aanbesteding niet genomen?

7. Welke maatregelen zijn er ten behoeve van logistiek genomen om emissies over het volledige bouwproces te beperken?
    a. Waarom is het bij dit project gelukt om deze maatregelen door te voeren?
    b. Waarom lukt het in traditionele projecten niet om deze maatregelen door te voeren?
    c. Welke emissiebeperkende logistieke maatregelen zijn er in dit project niet genomen?

8. Welke maatregelen zijn er genomen om emissies uit de productie van bouwmaterialen te beperken?
    a. Waarom is het bij dit project gelukt om deze maatregelen door te voeren?
    b. Waarom lukt het in traditionele projecten niet om deze maatregelen door te voeren?
    c. Welke maatregelen om emissies uit de productie van bouwmaterialen te beperken zijn er in dit project niet genomen?

9. Denkt u dat het mogelijk was geweest om extra maatregelen te nemen in dit project? (Aanvullen tot BIMZEC en de vijf Green Practices)

Rol ontwikkelaar in het beperken van emissies (Deelvraag 4)

10. Op de invoering van welke maatregelen uit vraag 8 tot en met 11 heeft een ontwikkelaar weinig tot geen invloed?
    a. Hoe komt dat?
    b. Nemen andere partijen hier verantwoordelijkheid?
    c. Zou een ontwikkelaar moeten proberen toch meer invloed te krijgen?
    d. Etc.

11. Op de invoering van welke maatregelen uit vraag 8 tot en met 11 heeft een ontwikkelaar juist een grote invloed?
    a. Hoe komt dat?

12. Zou een ontwikkelaar een grotere invloed moeten proberen uit te oefenen op de emissies die tijdens het bouwproces door verschillende ketenpartners worden uitgestoten?

13. Wat denkt u dat er bij u en andere ontwikkelaars moet veranderen als u als opdrachtgever maximale invloed wilt uitoefenen over de emissies uit het bouwproces?

14. Wat heeft een ontwikkelaar in dit proces nodig van andere interne en externe actoren om deze invloed maximaal te benutten?
    a. In welke fasen?
    b. Van welke specifieke partijen?

Appendix III: Validation session planning and reactions to statements

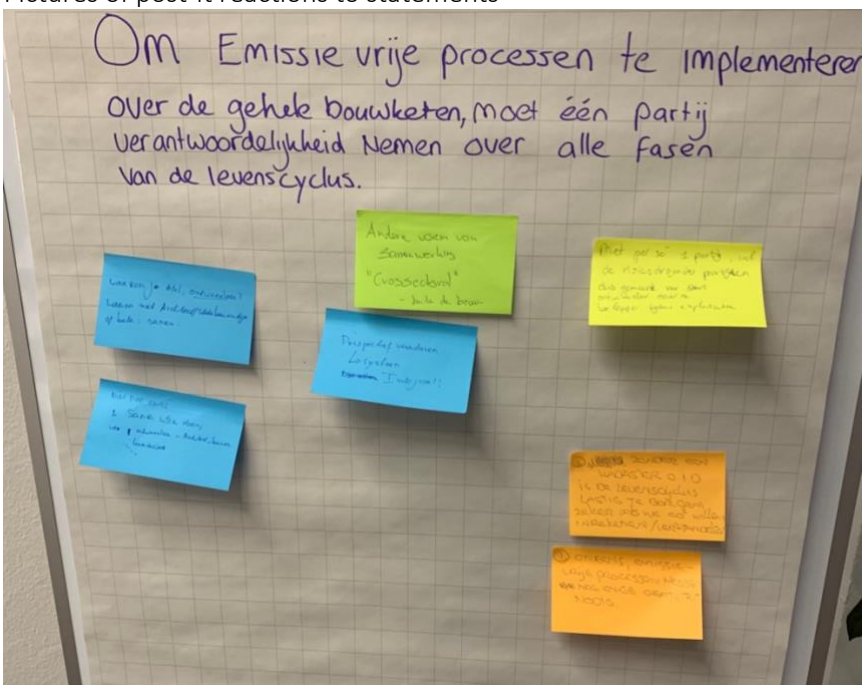
Planning:
14:00 - 14:15 Inloop, koffie & Welkom

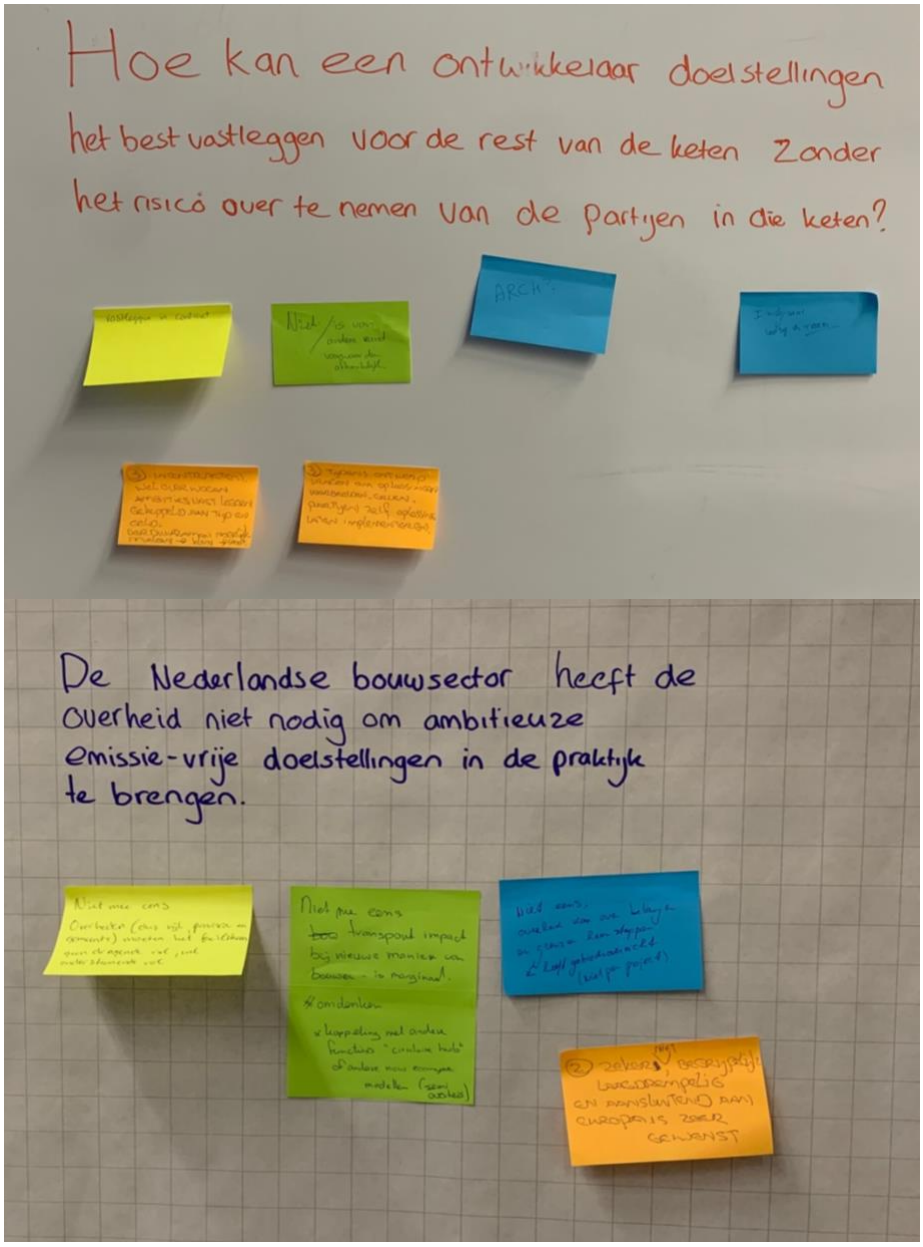
14:15 - 14:30 Presentatie Ward (toelichting onderzoek en uitleg stellingen)
14:30 - 14:45 Gallery walk Ward (deelnemers kunnen per stelling post-its plakken met eigen gedachte)
14:45 - 15:15 Discussie 3 x 10 minuten per poster/stelling

15:25 - 15:40 Presentatie Jelmar (toelichting onderzoek en uitleg stellingen)
15:40 - 15:55 Gallery walk Jelmar (deelnemers kunnen per stelling post-its plakken met eigen gedachte)
15:55 - 16:25 Discussie 3 x 10 minuten per poster/stelling

16:25 - 16:40 Wrap-up
16:40 - 17:00 uitloop/napraten

Pictures of post-it reactions to statements




Hoe kan een ontwikkelaar doelstellingen het best vastleggen voor de rest van de keten zonder het risico over te nemen van de partijen in die keten?
De Nederlandse bouwsector heeft de overheid niet nodig om ambitieuze emissie-vrije doelstellingen in de praktijk te brengen.

Appendix IV: Informed consent form

Delft University of Technology
HUMAN RESEARCH ETHICS
INFORMED CONSENT TEMPLATES

Geachte heer/mevrouw,

U wordt uitgenodigd om deel te nemen aan een onderzoek genaamd "The project developer as low-emission supply chain integrator". Dit onderzoek wordt uitgevoerd door dhr. Jelmar Broekman van de TU Delft in samenwerking met stagebedrijf Synchroon projectontwikkeling B.V.

Het doel van dit onderzoek is om informatie te verzamelen over de rol van u en uw organisatie in het betreffende project en de mate waarin lage emissie bouwmethoden in de samenwerking met andere ketenpartners in dit project worden besproken en gerealiseerd. Het interview zal ongeveer 60 minuten in beslag nemen. De data zal gebruikt worden voor;

- Publicatie op de TU Delft academic repository.
- Presentaties op de TU Delft, bij Synchroon projectontwikkeling B.V. en aan marktpartijen in het project: 'emission free highrise construction in the G4 cities'.
- Publiek toegankelijke verdediging van de thesis.

U wordt gevraagd om vanuit het perspectief van u en uw organisatie antwoord te geven op een aantal vragen over het beperken van emissies uit bouwprocessen en de samenwerking met ketenpartners in het ontwikkel- en bouwproces.

Zoals bij elke (online) activiteit is het risico van een databreuk aanwezig. Wij doen ons best om uw antwoorden vertrouwelijk te houden. We minimaliseren de risico's door informatie te anonimiseren en geen onnodige persoonsgegevens van u te vragen. De data wordt opgeslagen op een beveiligde server van de TU Delft en in een beveiligde cloud van de TU Delft.

Uw deelname aan dit onderzoek is volledig vrijwillig, en **u kunt zich elk moment terugtrekken zonder reden op te geven**. U bent vrij om vragen niet te beantwoorden. De conclusies en het transcript van het interview zullen na verwerking met u worden gedeeld, zodat u deze kunt controleren. Het is mogelijk om aanpassingen aan te vragen of om informatie te verwijderen tot 11 december 2023.

Voor vragen kunt u contact opnemen met dhr. Broekman door de mailen naa[redacted]f de spervisor ir. R. Vrijhoef door te mailen na[redacted]

Stemt u in met de verwerking van de door verstrekte informatie in het het onderzoek onder de hierboven vermelde voorwaarden? Alvast hartelijk bedankt voor uw medewerking!

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
A: GENERAL AGREEMENT – RESEARCH GOALS, PARTICPANT TASKS AND VOLUNTARY PARTICIPATION		
1. Ik heb de informatie over het onderzoek gedateerd [datum] gelezen en begrepen, of deze is aan mij voorgelezen. Ik heb de mogelijkheid gehad om vragen te stellen over het onderzoek en mijn vragen zijn naar tevredenheid beantwoord.	☐	☐
2. Ik doe vrijwillig mee aan dit onderzoek, en ik begrijp dat ik kan weigeren vragen te beantwoorden en mij op elk moment kan terugtrekken uit de studie, zonder een reden op te hoeven geven.	☐	☐
3. Ik begrijp dat mijn deelname aan het onderzoek de volgende punten betekent: Deelname aan het onderzoek zal worden vastgelegd via de volgende media	☐	☐

1

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
- Audio opnames van het interview, welke na transcriptie zullen worden vernietigd. - Gepseudonimiseerde transcripties van het interview als tekstbestand.		
4. Ik begrijp dat mijn deelname aan het onderzoek niet wordt gecompenseerd.	☐	☐
5. Ik begrijp dat de studie "The project developer as low-emission supply chain integrator" eindigt op vrijdag 19 januari 2024 met een publieke verdediging van de master thesis..		
B: POTENTIAL RISKS OF PARTICIPATING (INCLUDING DATA PROTECTION)		
6. Ik begrijp dat mijn deelname de volgende risico's met zich meebrengt; - .mp3-bestanden van het interview kunnen lekken naar externe partijen in het geval van een data lek. - Mogelijk zijn lezers in staat u toch te identificeren door geanonimiseerde data zorgvuldig te lezen, wanneer zij goed op de hoogte zijn van uw werkzaamheden in het case studie project. Informatie over samenwerking met andere partijen kan hierdoor naar deze partijen lekken en schade toebrengen aan uw samenwerking. Ik begrijp dat deze risico's worden geminimaliseerd door; - Mp3- bestanden worden verwijderd zodra de transcripties zijn goedgekeurd door de participanten en kunnen daarna dus niet meer lekken. - Project data wordt opgeslagen op een veilige Onedrive locatie van de TU Delft, waartoe enkel Dhr. Broekman en zijn supervisors toegang hebben. - Er zal geen onnodige gevoelige informatie gevraagd worden te delen over het project en uw samenwerking.	☐	☐
7. Ik begrijp dat mijn deelname betekent dat er persoonlijke identificeerbare informatie en onderzoek data worden verzameld, met het risico dat ik hieruit geïdentificeerd kan worden.	☐	☐
9. Ik begrijp dat de volgende stappen worden ondernomen om het risico van een databreuk te minimaliseren, en dat mijn identiteit op de volgende manieren wordt beschermd in het geval van een databreuk: - Data wordt opgeslagen op een afgeschermde Onedrive locatie van het projectteam van de TU Delft - Transcripties worden gepseudonimiseerd - Audio-bestanden worden verwijderd na transcriptie.	☐	☐
10. Ik begrijp dat de persoonlijke informatie die over mij verzameld wordt en mij kan identificeren, zoals naam, e-mailadres, functie en werkgever, niet gedeeld worden buiten het studieteam.	☐	☐
11. Ik begrijp dat de persoonlijke data die over mij verzameld wordt, vernietigd wordt na goedkeuring van de transcripties door mij uiterlijk medio november 2023.	☐	☐
C: RESEARCH PUBLICATION, DISSEMINATION AND APPLICATION		

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
12. Ik begrijp dat na het onderzoek de geanonimiseerde informatie zal worden geüpload naar 4TU.ResearchData, wat publiek toegankelijk is.	☐	☐
13. Ik geef toestemming om mijn antwoorden, ideeën of andere bijdrages anoniem te quoten in resulterende producten.	☐	☐
D: (LONGTERM) DATA STORAGE, ACCESS AND REUSE		
16. Ik geef toestemming om de geanonimiseerde data in de vorm van transcripties die over mij verzameld worden gearchiveerd worden in de TU Delft repository, opdat deze gebruikt kunnen worden voor toekomstig onderzoek en onderwijs.	☐	☐
17. Ik begrijp dat de toegang tot deze repository openbaar is.	☐	☐

Signatures

_____ _____ _____

Naam deelnemer Handtekening Datum

Ik, **de wettelijke vertegenwoordiger**, verklaar dat de informatie en het instemmingsformulier aan de potentiële deelnemer correct zijn voorgelezen, en dat hij/zij de kans heeft gekregen om vragen te stellen. Ik verklaar dat de potentiële deelnemer zijn/haar instemming vrijwillig heeft gegeven.

_____ _____ _____

Naam wettelijke vertegenwoordiger Handtekening Datum

Ik, **de onderzoeker**, verklaar dat ik de informatie en het instemmingsformulier correct aan de potentiële deelnemer heb voorgelezen en, naar het beste van mijn vermogen, heb verzekerd dat de deelnemer begrijpt waar hij/zij vrijwillig mee instemt.

_____ _____ _____

J.J.F. Broekman (Jelmar Handtekening Datum

Contactgegevens van de onderzoeker voor verdere informatie: [Naam, telefoonnummer, emailadres]

Appendix V: HREC Checklist

Delft University of Technology
HUMAN RESEARCH ETHICS
CHECKLIST FOR HUMAN RESEARCH
(Version January 2022)

IMPORTANT NOTES ON PREPARING THIS CHECKLIST

1. An HREC application should be submitted for every research study that involves human participants (as Research Subjects) carried out by TU Delft researchers
2. Your HREC application should be submitted and approved **before** potential participants are approached to take part in your study
3. All submissions from Master's Students for their research thesis need approval from the relevant Responsible Researcher
4. The Responsible Researcher must indicate their approval of the completeness and quality of the submission by signing and dating this form OR by providing approval to the corresponding researcher via email (included as a PDF with the full HREC submission)
5. There are various aspects of human research compliance which fall outside of the remit of the HREC, but which must be in place to obtain HREC approval. These often require input from internal or external experts such as Faculty Data Stewards, Faculty HSE advisors, the TU Delft Privacy Team or external Medical research partners.
6. You can find detailed guidance on completing your HREC application here
7. Please note that incomplete submissions (whether in terms of documentation or the information provided therein) will be returned for completion **prior to any assessment**
8. If you have any feedback on any aspect of the HREC approval tools and/or process you can leave your comments here

I. Applicant Information

PROJECT TITLE:	
Research period: *Over what period of time will this specific part of the research take place*	**09/2023 – 02/2024**
Faculty:	**Architecture, Urbanism & Building Sciences**
Department:	**Management in the Built Environment**
Type of the research project: *(Bachelor's, Master's, DreamTeam, PhD, PostDoc, Senior Researcher, Organisational etc.)*	**Master's thesis**
Funder of research: *(EU, NWO, TUD, other – in which case please elaborate)*	**The research is supervised by the TU Delft in collaboration with a graduation company; Synchroon projectontwikkeling b.v. The latter pays the student an internship compensation.**
Name of Corresponding Researcher: *(If different from the Responsible Researcher)*	**J. J. F. Broekman**
E-mail Corresponding Researcher: *(If different from the Responsible Researcher)*	[redacted]
Position of Corresponding Researcher: *(Masters, DreamTeam, PhD, PostDoc, Assistant/ Associate/ Full Professor)*	
Name of Responsible Researcher: ***Note:** all student work must have a named Responsible Researcher to approve, sign and submit this application*	**Dr.Ir. R. (Ruben) Vrijhoef**
E-mail of Responsible Researcher: *Please ensure that an institutional email address (**no Gmail, Yahoo, etc.**) is used for all project documentation/ communications including Informed Consent materials*	[redacted]
Position of Responsible Researcher : *(PhD, PostDoc, Associate/ Assistant/ Full Professor)*	**Researcher**

II. Research Overview

***NOTE:** You can find more guidance on completing this checklist here*

a) Please summarise your research very briefly (100-200 words)

What are you looking into, who is involved, how many participants there will be, how they will be recruited and what are they expected to do?

Add your text here – (please avoid jargon and abbrevations)
As part of a case study research, in which 4 cases will be reviewd, 2 or 3 participants will be selected per case to canduct an interview with. The are expected to share their experiences in the case study projects.

b) **If your application is an additional project** related to an existing approved HREC submission, please provide a brief explanation including the existing relevant HREC submission number/s.

Add your text here – (please avoid jargon and abbrevations)
?

III. Risk Assessment and Mitigation Plan

NOTE: You can find more guidance on completing this checklist here

Please complete the following table in full for all points to which your answer is "yes". Bear in mind that the vast majority of projects involving human participants as Research Subjects also involve the collection of **Personally Identifiable Information (PII)** and/or **Personally Identifiable Research Data (PIRD)** which may pose potential risks to participants as detailed in Section G: Data Processing and Privacy below.

To ensure alignment between your risk assessment, data management and what you agree with your Research Subjects you can use the last two columns in the table below to refer to specific points in your Data Management Plan (DMP) and Informed Consent Form (ICF) **– but this is not compulsory**.

It's worth noting that **you're much more likely to need to resubmit your application if you neglect to identify potential risks**, than if you identify a potential risk and demonstrate how you will mitigate it. If necessary, the HREC will always work with you and colleagues in the Privacy Team and Data Management Services to see how, if at all possible, your research can be conducted.

			If YES please complete the Risk Assessment and Mitigation Plan columns below.		*Please provide the relevant reference #*	
ISSUE	**Yes**	**No**	**RISK ASSESSMENT – what risks could arise?** *Please ensure that you list ALL of the actual risks that could potentially arise – do not simply state whether you consider any such risks are important!*	**MITIGATION PLAN – what mitigating steps will you take?** *Please ensure that you summarise what actual mitigation measures you will take for each potential risk identified – do not simply state that you will e.g. comply with regulations.*	**DMP**	**ICF**
A: Partners and collaboration						
1. Will the research be carried out in collaboration with additional organisational partners such as: • One or more collaborating research and/or commercial organisations • Either a research, or a work experience internship provider[1] *[1] If yes, please include the graduation agreement in this application*	**Yes**		- No Risk, since no sensitive data which could give other a competitive or commercial advantage will be published.	- To ensure that this will not happen no unescesary data will be collected and the sensitive data will be stored on a secure TU Delft one drive and not be saherd with third parties until after graduation.	x	
2. Is this research dependent on a Data Transfer or Processing Agreement with a collaborating partner or third party supplier? *If yes please provide a copy of the signed DTA/DPA*		**No**				
3. Has this research been approved by another (external) research ethics committee (e.g.: HREC and/or MREC/METC)? *If yes, please provide a copy of the approval (if possible) and summarise any key points in your Risk Management section below*		**No**				
B: Location						
4. Will the research take place in a country or countries, other than the Netherlands, within the EU?		**No**				

			If YES please complete the Risk Assessment and Mitigation Plan columns below.		*Please provide the relevant reference #*	
ISSUE	**Yes**	**No**	**RISK ASSESSMENT – what risks could arise?** *Please ensure that you list ALL of the actual risks that could potentially arise – do not simply state whether you consider any such risks are important!*	**MITIGATION PLAN – what mitigating steps will you take?** *Please ensure that you summarise what actual mitigation measures you will take for each potential risk identified – do not simply state that you will e.g. comply with regulations.*	**DMP**	**ICF**
5. Will the research take place in a country or countries outside the EU?		**No**				
6. Will the research take place in a place/region or of higher risk – including known dangerous locations (in any country) or locations with non-democratic regimes?		**No**				
C: Participants						
7. Will the study involve participants who **may** be vulnerable and possibly (legally) unable to give informed consent? (e.g., children below the legal age for giving consent, people with learning difficulties, people living in care or nursing homes.).		**No**				
8. Will the study involve participants who **may** be vulnerable under specific circumstances and in specific contexts, such as victims and witnesses of violence, including domestic violence; sex workers; members of minority groups, refugees, irregular migrants or dissidents?		**No**				
9. Are the participants, outside the context of the research, in a dependent or subordinate position to the investigator (such as own children, own students or employees of either TU Delft and/or a collaborating partner organisation)? *It is essential that you safeguard against possible adverse consequences of this situation (such as allowing a student's failure to participate to your satisfaction to affect your evaluation of their coursework).*		**No**				
10. Is there a high possibility of re-identification for your participants? (e.g., do they have a very specialist job of which there are only a small number in a given country, are they members of a small community, or employees from a partner company collaborating in the research? Or are they one of only a handful of (expert) participants in the study?	**Yes**		Information provided by the participant on the collaboration with other stakeholders in case study projects can have a negative effect on the relationships between these organizations. This could damage the organizations and participants involved.	- Participants will be informed on the channels through which the thesis will be shared. - The audio files of the interviews will be deleted after transcribation and the transcripts will be validated by the participant before publication. - Transcripts will be pseudonomysed. By doing this the case study projects and the names of the interviewed stakeholders will not by stored and known outside the project team. Therefore participants and their organizations cannot be identiefied. - On top of this, participants are warned of such risks before participation.	x	x
D: Recruiting Participants						

			If YES please complete the Risk Assessment and Mitigation Plan columns below.		*Please provide the relevant reference #*	
ISSUE	**Yes**	**No**	**RISK ASSESSMENT – what risks could arise?** *Please ensure that you list ALL of the actual risks that could potentially arise – do not simply state whether you consider any such risks are important!*	**MITIGATION PLAN – what mitigating steps will you take?** *Please ensure that you summarise what actual mitigation measures you will take for each potential risk identified – do not simply state that you will e.g. comply with regulations.*	**DMP**	**ICF**
11. Will your participants be recruited through your own, professional, channels such as conference attendance lists, or through specific network/s such as self-help groups	**yes**		The information will be provided by a select group of people related to my personel network and the network of Synchroon Projectontwikkeling B.V. This could mean that conclusions will be difficult to transfer to a different context.	- Next to case studies at Synchroon projectontwikkeling B.V. other project developers will be aprouched to participate in the research. - By also involving other organizations and not stating which project are from outside Synchroon. Readers cannot find out who has participated in the research.		
12. Will the participants be recruited or accessed in the longer term by a (legal or customary) gatekeeper? (e.g., an adult professional working with children; a community leader or family member who has this customary role – within or outside the EU; the data producer of a long-term cohort study)		**No**				
13. Will you be recruiting your participants through a crowd-sourcing service and/or involve a third party data-gathering service, such as a survey platform?		**No**				
14. Will you be offering any financial, or other, remuneration to participants, and might this induce or bias participation?		**No**				
E: Subject Matter *Research related to medical questions/health may require special attention. See also the website of the **CCMO** before contacting the HREC.*						
15. Will your research involve any of the following: • Medical research and/or clinical trials • Invasive sampling and/or medical imaging • Medical and *In Vitro Diagnostic Medical* Devices Research		**No**				
16. Will drugs, placebos, or other substances (e.g., drinks, foods, food or drink constituents, dietary supplements) be administered to the study participants? *If yes see here to determine whether medical ethical approval is required*		**No**				
17. Will blood or tissue samples be obtained from participants? *If yes see here to determine whether medical ethical approval is required*		**No**				
18. Does the study risk causing psychological stress or anxiety beyond that normally encountered by the participants in their life outside research?		**No**				
19. Will the study involve discussion of personal sensitive data which could put participants at increased legal, financial, reputational, security or other risk? (e.g., financial data, location data, data relating to children or other vulnerable groups) *Definitions of sensitive personal data, and special cases are provided on the TUD Privacy Team website.*		**No**				

			If YES please complete the Risk Assessment and Mitigation Plan columns below.		*Please provide the relevant reference #*	
ISSUE	**Yes**	**No**	**RISK ASSESSMENT – what risks could arise?** *Please ensure that you list ALL of the actual risks that could potentially arise – do not simply state whether you consider any such risks are important!*	**MITIGATION PLAN – what mitigating steps will you take?** *Please ensure that you summarise what actual mitigation measures you will take for each potential risk identified – do not simply state that you will e.g. comply with regulations.*	**DMP**	**ICF**
20. Will the study involve disclosing commercially or professionally sensitive, or confidential information? (e.g., relating to decision-making processes or business strategies which might, for example, be of interest to competitors)	**Yes**		Participants can share data that can harm their own company or project partners, since it could leak their stragegies.	- I will ask them not to share sensitive information and after pseudonomysed transcription, the recordings will be deleted. - I will not collect names of companies, projects or individuals, so participants and participating companies will be very hard, if not impossible, to identify. - On top of this, participants are warned of such risks before participation.	x	x
21. Has your study been identified by the TU Delft Privacy Team as requiring a Data Processing Impact Assessment (DPIA)? *If yes please attach the advice/ approval from the Privacy Team to this application*		**NO**				
22. Does your research investigate causes or areas of conflict? *If yes please confirm that your fieldwork has been discussed with the appropriate safety/security advisors and approved by your Department/Faculty.*		**NO**				
23. Does your research involve observing illegal activities or data processed or provided by authorities responsible for preventing, investigating, detecting or prosecuting criminal offences *If so please confirm that your work has been discussed with the appropriate legal advisors and approved by your Department/Faculty.*		**NO**				
F: Research Methods						
24. Will it be necessary for participants to take part in the study without their knowledge and consent at the time? (e.g., covert observation of people in non-public places).		**NO**				
25. Will the study involve actively deceiving the participants? (For example, will participants be deliberately falsely informed, will information be withheld from them or will they be misled in such a way that they are likely to object or show unease when debriefed about the study).		**NO**				
26. Is pain or more than mild discomfort likely to result from the study? And/or could your research activity cause an accident involving (non-) participants?		**NO**				
27. Will the experiment involve the use of devices that are not 'CE' certified? *Only, if 'yes': continue with the following questions:*		**NO**				
• Was the device built in-house?						
• Was it inspected by a safety expert at TU Delft? *If yes, please provide a signed **device report***						

			If YES please complete the Risk Assessment and Mitigation Plan columns below.		*Please provide the relevant reference #*	
ISSUE	**Yes**	**No**	**RISK ASSESSMENT – what risks could arise?** *Please ensure that you list ALL of the actual risks that could potentially arise – do not simply state whether you consider any such risks are important!*	**MITIGATION PLAN – what mitigating steps will you take?** *Please ensure that you summarise what actual mitigation measures you will take for each potential risk identified – do not simply state that you will e.g. comply with regulations.*	**DMP**	**ICF**
• If it was not built in-house and not CE-certified, was it inspected by some other, qualified authority in safety and approved? *If yes, please provide records of the inspection*						
28. Will your research involve face-to-face encounters with your participants and if so how will you assess and address Covid considerations?	**Yes**		Strict covid regulations have been lifted in the Netherlands, but I won't visit a participant when one of the participants to an interview or session shows symptoms.	A digital meeting could be the solution in this case.		
29. Will your research involve **either:** a) "big data", combined datasets, new data-gathering or new data-merging techniques which might lead to re-identification of your participants **and/or** b) artificial intelligence or algorithm training where, for example biased datasets could lead to biased outcomes?		**No**				
G: Data Processing and Privacy						
30. Will the research involve collecting, processing and/or storing any directly identifiable PII (Personally Identifiable Information) including name or email address that will be used for administrative purposes only? (eg: obtaining Informed Consent or disbursing remuneration)	**Yes**		When stored in the same location as the pseudonomysed transcripts, the names on the consent forms could be linked to the transcrips by people close to the participants.	On the informed consent forms, participants are asked to sign with the name and signature. These forms will be stored in a different secure folder to which only I have access.	**x**	**x**
31. Will the research involve collecting, processing and/or storing any directly or indirectly identifiable PIRD (Personally Identifiable Research Data) including videos, pictures, IP address, gender, age etc and **what other Personal Research Data** (including personal or professional views) will you be collecting?	**Yes**		Audio recordings of the interviews could leak and peoples voices could be recognized.	The recordings will be deleted as soon as possible. After the transcripts are approved by the participants, the mp3.file will be deleted. The mp3 files will never be stored on external rrecording devices longer than iyt takes to upload the files to the secure Onedrive project folder.	x	x
32. Will this research involve collecting data from the internet, social media and/or publicly available datasets which have been originally contributed by human participants	Yes		Yes, research papers will form the basis of the thesis.			
33. Will your research findings be published in one or more forms in the public domain, as e.g., Masters thesis, journal publication, conference presentation or wider public dissemination?	**Yes**		The thesis will be published on the public available TU Delft educational repository.	All data will be pseudonomysed by then and participants will have signed consent forms and have approved their transcripts.	x	x
34. Will your research data be archived for re-use and/or teaching in an open, private or semi-open archive?	**Yes**		Same as the above.	Same as the above.	x	x

Appendix VI: Data Management Plan

Plan Overview

A Data Management Plan created using DMPonline

Title: Master Thesis Jelmar Broekman

Creator: Jelmar Broekman

Principal Investigator: Jelmar Broekman

Data Manager: Jelmar Broekman

Project Administrator: Jelmar Broekman

Affiliation: Delft University of Technology

Template: TU Delft Data Management Plan template (2021)

Project abstract:

In the Netherlands, reducing nitrogen emissions has become an important topic over the last decades and has become a crisis in recent years. The government has launched a program to significantly limit the number of nitrogen emissions as well as other harmful substances like greenhouse gasses and particle matters by 2030, called the clean and emission-free construction policy. Parallel to the environmental concerns construction pace needs to be increased to solve the housing crisis. Multiple municipalities, universities and market parties are now doing research into several alternative construction methods and types of construction logistics to investigate the possibilities for an emission-free construction process for inner-city high-rise buildings. This thesis investigates changing the supply-chain configuration can benefit implementation of emission-free practices.

To identify barriers and drivers in the supply chain Supply chains of multiple case study project will be analysed by performing semi-structured interviews with supply chain actors. The implementation of industrialization, modular construction, bio-based construction, zero emission-processes and circular construction techniques on the main structure and façade will be the focus. According to the barriers and drivers that possibly arise a new blueprint for the construction supply chain will be created. This blueprint will be the topic of discussion for an expert panel, including people from all stages of the supply chain.

ID: 133818

Start date: 13-02-2023

End date: 19-01-2024

Last modified: 03-10-2023

Master Thesis Jelmar Broekman

0. Administrative questions

1. Name of data management support staff consulted during the preparation of this plan.

My faculty data steward, Janine Strandberg, has reviewed this DMP on 26-09-2023.

2. Date of consultation with support staff.

2023-09-26

I. Data description and collection or re-use of existing data

3. Provide a general description of the type of data you will be working with, including any re-used data:

Type of data	File format(s)	How will data be collected (for re-used data: source and terms of use)?	Purpose of processing	Storage location	Who will have access to the data

Recorded interviews in which the participant is asked to elaborate on their position within a project and organization, without naming exact company or project name.	.mp3	Recorded by an audio recorder on smartphone or laptop. These recordings will be deleted after the transcriptions have been approved by the participant.	To collect data on experiences of the participant in the case study projects. In order to answer the following research questions: 1. What are the most impactful steps and actors in the construction supply-chain to influence implementation of low-emission methods for high-rise construction in Dutch cities? 1. What steps and actors external to the supply-chain influence the implementation of low-emission methods for high-rise construction in Dutch cities? 1. What drives different actors to implement low-emission methods for high-rise construction in Dutch cities? 1. What methods and practices in the supply chain beneficial to the implementation of low-emission methods for high-rise construction in Dutch cities are already put to practice and what are currently missing? 1. How can real estate developers promote these low-emission methods and practices for high-rise construction supply chains in Dutch cities?	The smartphone is used as an temporary storage space in case the laptop recordings fail. Right after the interview, when it becomes clear the laptop recording is successful, the mp3 file will be deleted from the smartphone. Stored at the TU Delft one-drive used for the project.	Student & Supervisors: Jelmar Broekman - MSc. thesis student Ruben Vrijhoef - responsible researcher and 1st thesis mentor Stijn Brancart - professor and 2nd mentor Petar Koljensic - Junior researcher and 3rd mentor.
Pseudenomysed Interview Transcripts	.docx	The transcript will be created by using the mp3 files.	To be able to read, code and possibly cite the interviewees. To pseudonymised the information from the interviews.	Stored at the TU Delft one-drive used for the project.	Student & Supervisors

Recordings of validation session combined with notes of time stamps when wich participant is speaking (pseudenomysed).	.mp3	Recorded by an audio recorder on smartphone or laptop. These recordings will be deleted after the transcriptions have been approved by the participant.	To collect information and feedback on the result of my research and to spark discusion among different stakeholders to look for solutions. mp4 instead of mp3, because voices can be difficult to set apart without image.	Stored at the TU Delft one-drive used for the project. This session will be organized in combination with another master student, who is part of the same research group and is guided by the same supervisors. He won't have access to my folder, but we'll create a shared folder for this session.	Student, Supervisors and Fellow master student: Ward Willems
Transcript of validation session	.docx	The transcript will be created by using the mp4 file	To be able to read, code and possibly cite the participants. To pseudenomyse the information from the participants.	Stored at the TU Delft one-drive used for the project.	Student & Supervisors

4. How much data storage will you require during the project lifetime?

- < 250 GB

II. Documentation and data quality

5. What documentation will accompany data?

- Methodology of data collection
- Data will be deposited in a data repository at the end of the project (see section V) and data discoverability and re-usability will be ensured by adhering to the repository's metadata standards
- README file or other documentation explaining how data is organised

III. Storage and backup during research process

6. Where will the data (and code, if applicable) be stored and backed-up during the project lifetime?

- OneDrive

As discussed with my project team (supervisors), we will not use the TU Delft project storage, but will keep using Onedrive for this research project. The data collected can hardly damage the participants, is pseudenomysed very quickly and the participants are informed about the entire data collection- and management proces beforehand.

IV. Legal and ethical requirements, codes of conduct

7. Does your research involve human subjects or 3rd party datasets collected from human participants?

- Yes

8A. Will you work with personal data? (information about an identified or identifiable natural person)

If you are not sure which option to select, first ask your Faculty Data Steward for advice. You can also check with the privacy website . If you would like to contact the privacy team: privacy-tud@tudelft.nl, please bring your DMP.

- Yes

People could find out who was interviewed by linking the position (project developer, contractor, project manager) to the cases. Therefore the cases as well as the participants position within these project will be completely pseudonomysed.

8B. Will you work with any other types of confidential or classified data or code as listed below? (tick all that apply)

If you are not sure which option to select, ask your Faculty Data Steward for advice.

- Yes, confidential data received from commercial, or other external partners

Parties within a construction project will share information on their collaboration with other partners. This could damage the relations between the project partners. As mentioned in the questions above. Measures are taken to withhold the participants of sharing this data, their projects, companies and roles are pseudonomysed and personal identifiable data is deleted right after approval of the pseudonomysed transcripts.

9. How will ownership of the data and intellectual property rights to the data be managed?

For projects involving commercially-sensitive research or research involving third parties, seek advice of your Faculty Contract Manager when answering this question. If this is not the case, you can use the example below.

The datasets underlying the published papers will be publicly released following the TU Delft Research Data Framework Policy. During the active phase of research, the project leader from TU Delft will oversee the access rights to data (and other outputs), as well as any requests for access from external parties. They will be released publicly no later than at the time of publication of corresponding research papers.

In my internship agreement, Me and the TU Delft project team own the data related to my graduation project.

10. Which personal data will you process? Tick all that apply

- Other types of personal data - please explain below
- Email addresses and/or other addresses for digital communication
- Signed consent forms
- Photographs, video materials, performance appraisals or student results
- Data collected in Informed Consent form (names and email addresses)

- Opinions/ beliefs
- Audio Recordings

11. Please list the categories of data subjects

Individuals that work at project developing companies, contractors, architecture firms, municipalities, other government bodies, material suppliers & manufacturers

12. Will you be sharing personal data with individuals/organisations outside of the EEA (European Economic Area)?

- No

15. What is the legal ground for personal data processing?

- Informed consent

16. Please describe the informed consent procedure you will follow:

All study participants will be asked for their written consent for taking part in the study and for data processing before the start of the interview or panel session.

17. Where will you store the signed consent forms?

- Same storage solutions as explained in question 6

18. Does the processing of the personal data result in a high risk to the data subjects?

If the processing of the personal data results in a high risk to the data subjects, it is required to perform a Data Protection Impact Assessment (DPIA). In order to determine if there is a high risk for the data subjects, please check if any of the options below that are applicable to the processing of the personal data during your research (check all that apply).
If two or more of the options listed below apply, you will have to complete the DPIA. Please get in touch with the privacy team: privacy-tud@tudelft.nl to receive support with DPIA.
If only one of the options listed below applies, your project might need a DPIA. Please get in touch with the privacy team: privacy-tud@tudelft.nl to get advice as to whether DPIA is necessary.
If you have any additional comments, please add them in the box below.

- Systematic monitoring

19. Did the privacy team advise you to perform a DPIA?

- No

22. What will happen with personal research data after the end of the research project?

- Personal research data will be destroyed after the end of the research project
- Anonymised or aggregated data will be shared with others

23. How long will (pseudonymised) personal data be stored for?

- 10 years or more, in accordance with the TU Delft Research Data Framework Policy

24. What is the purpose of sharing personal data?

- For research purposes, which are in-line with the original research purpose for which data have been collected

25. Will your study participants be asked for their consent for data sharing?

- Yes, in consent form - please explain below what you will do with data from participants who did not consent to data sharing

V. Data sharing and long-term preservation

27. Apart from personal data mentioned in question 22, will any other data be publicly shared?

- All other non-personal data (and code) produced in the project

29. How will you share research data (and code), including the one mentioned in question 22?

- All anonymised or aggregated data, and/or all other non-personal data will be uploaded to 4TU.ResearchData with public access

30. How much of your data will be shared in a research data repository?

- < 100 GB

31. When will the data (or code) be shared?

- At the end of the research project

32. Under what licence will be the data/code released?

- CC0

VI. Data management responsibilities and resources

33. Is TU Delft the lead institution for this project?

- Yes, leading the collaboration - please provide details of the type of collaboration and the involved parties below

Synchroon projectontwikkeling B.V. is the graduation company offering an internship and data.
The graduation research will provide input for a research group existing of both public parties, universities and sector actors. This research is called 'geïndustrialiseerde lage emissie hoogbouw in de G4'.

34. If you leave TU Delft (or are unavailable), who is going to be responsible for the data resulting from this project?

The Head of the Department of the Best Experiments (hod-bestexperiments@tudelft.nl)

35. What resources (for example financial and time) will be dedicated to data management and ensuring that data will be FAIR (Findable, Accessible, Interoperable, Re-usable)?

4TU.ResearchData is able to archive 1TB of data per researcher per year free of charge for all TU Delft researchers. We do not expect

to exceed this and therefore there are no additional costs of long term preservation.