SMALL AND MEDIUM SIZED ENTERPRISES' CONSTRUCTION LOGISTICS IN URBAN AREAS

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Small and medium sized enterprises' construction logistics in urban areas

A framework to decrease the emissions caused by small-scale construction projects' logistics in urban areas

By

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PREFACE

This thesis project is the final step in the curriculum of the master's program Engineering and Policy Analysis (EPA). The focus during this master's program lies in analyzing grand challenges and to come up with information and solutions for decision makers to deal with those challenges. The purpose of this thesis project has been to analyze small-scale construction projects' logistics and to come up with innovative logistics solutions that can be applied by them. These innovative solutions will contribute to either fewer transport movements and/or less emissions which will lead to combat climate change.

The process of writing this thesis project was new to me in two ways. My bachelor's thesis project was about a topic in which the University of Groningen needed my help with. The guidance during that project was much more straightforward than this master's thesis project has been. The set-up of the applied methods and data gathering needs to be done by myself with the assistance of my supervisors. To do something like that for such a large project was something I have not done before which made it difficult during the process. The second thing which was new was that I performed research not only for the university but also for an external organization: TNO. The goal was to find a good balance in the information that TNO needed and to stay academically oriented. This was a new experience that I found interesting. I think that in this way the thesis project has been applied in a way that the project includes the actual perspectives of reality.

During the process, I discovered that there are many problems withholding logistics solutions to be adopted and initiated. These problems made it difficult for me to think about how to deal with finding effective solutions. However, at one moment I did not focus on the problems anymore but focused on the opportunities to overcome those problems which made me more optimistic instead of pessimistic about the results of this thesis project.

During my thesis project, several people helped me which I would like to thank. Firstly, I would like to thank my first supervisor Marcel Ludema. Our meetings and your feedback gave me the directions I needed to fulfill my research. Secondly, I would like to thank Bert Enserink to give me feedback during the formal moments. These formal moments with the graduation committee, the kick-off meeting and green light meeting, were highly unusual and thus unforgettable because we had them online on Microsoft Teams due to the circumstances of COVID-19. Thirdly, I would like to thank TNO and especially Siem van Merriënboer for the assistance in this process. We have had many meetings where we were finding solutions for the problem together. Our communication and your positive feedback gave me the confidence to keep on going with reaching my goal.

Lastly, I would like to thank my family. You have supported me all the way during my long (and sometimes intense) period of study. Without your help, it would have been a lot harder or maybe impossible to earn my bachelor's and master's degrees.

SUMMARY

The world is facing climate change which has severe impacts on extreme weather events, biodiversity and rising seas. Greenhouse gas emissions need to be reduced to counteract climate change. As a result, the Paris Agreement has been signed. The Netherlands has reshaped this agreement into its own agreement called the Dutch climate agreement with a goal to reduce greenhouse gas emissions with 49% compared to 1990. One specific way to contribute to that reduction is setting Zero-Emission (ZE) zones to ban fossil fuel vehicles in urban areas which will presumably lead to a reduction of 1.0 Mton CO_2 (Overheid, 2019). The ZE zones will be initiated from 2025 in the 30-40 largest municipalities in the Netherlands for passenger cars and delivery vans. There is an exemption for heavy transport on the ZE zones. Box trucks younger than five years and tractors younger than eight years with Euro VI emission standards are allowed to enter the ZE zones until 2030. The majority of the population lives in urban areas and that share will only increase in the future. That population suffers from nuisance and vehicle related emissions. A contributing fact of the ZE zones is that the nuisance of construction transport will be decreased. Out of all traffic in urban areas, 30% is construction-related. That means that the construction related transport movements need to be prepared for the upcoming ZE zones.

The goal of the research is to find logistics solutions and to communicate the findings in a way that the relevant stakeholders of construction logistics are aware of this problem and know which logistics solutions can be applied in urban areas. These logistics solutions will reduce the emissions and transport movements to contribute to the Dutch climate agreement goal of 1.0 Mton CO_2 reduction by setting the ZE zones. Moreover, logistics solutions will increase the livability and accessibility of urban areas.

There is a necessity to find logistics solutions for small-scale construction projects because of two reasons. The first reason is that research has not been conducted on small-scale construction projects before. Hence, there is a knowledge gap in this specific domain within construction logistics. The second reason is that small-scale construction projects are executed by SME (small and medium-sized enterprises) contractors that do not have the resources for innovation. The methods used are literature review, semi-structured interviews, stakeholder analysis and a basic design cycle.

The research has been structured with a main research question in order to meet the goal of the research. The following main research question is asked and answered with this thesis project:

Which logistics solutions fit the requirements of small-scale construction projects in urban areas with the purpose of minimizing transport movements and emissions, that can be adopted by the relevant stakeholders?

Five subquestions are answered in order to answer the main research question. These five subquestions are:

1. *What are the characteristics of small and medium sized projects executed by SMEs?*
2. *What are the current logistics structures for small-scale construction projects?*
3. *How do the objectives and roles of the various stakeholders involved affect the transport movements in construction logistics?*

4. *What are feasible logistics solutions to generate transport efficiency and sustainability?*
5. *How can the relevant stakeholders be informed about the urgency of the problem and the feasible logistics solutions for small-scale construction projects?*

There are two research approaches applied during this thesis project. The first three subquestions are answered with an inductive approach and the last two subquestions are answered with a deductive approach. The final product is a printable booklet to communicate that is developed by using the basic design cycle that has been adjusted for this thesis project (see Figure 1). The first three subquestions are used for the analysis step that leads to a list of design requirements. These design requirements are separated into requirements that the feasible logistics solutions must have to answer subquestion 4 and into design requirements that the product must have to answer subquestion 5. The synthesis is the development of the list of logistics solutions and the design of the product. In the end, the product's design has been approved after the product's user (a contractor) has validated the design and after evaluations of the product.

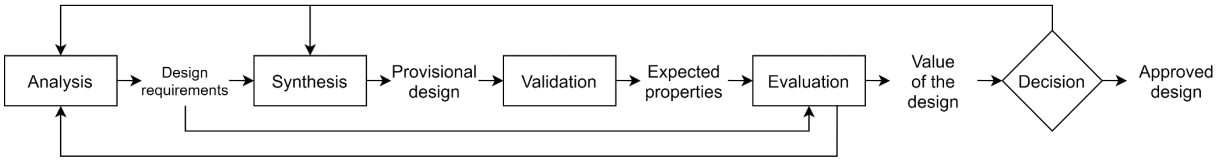

Figure 1: Adjusted basic design cycle based on Roozenburg and Eekels (1995)

1. What are the characteristics of small and medium sized projects executed by SMEs?

The research started with the definition of small-scale construction projects. The literature review resulted in how to classify small-scale construction projects into groups. First, the enterprises working in the construction sector are analyzed to know more about the SMEs because these are the backbone of the economy. The construction sector consists mostly out of small enterprises because 97.2% of all construction enterprises have less than 10 employees. Moreover, 83.7% of that 97.2% have one employee in the enterprise (freelancers). Afterward, the projects have been grouped on the project's size in squared meter gross floor area (GFA) and on total construction costs. The difference between these groups is necessary to structure the small-scale construction projects on logistics characteristics and finally on feasible logistics solutions. The three groups are micro (<150 m^2; <€0.3 mln), small (150 – 1,000 m^2; €0.3 mln – €3 mln) and medium (1,000 – 10,000 m^2; €3 mln - €20 mln).

The different types of construction projects are new construction, renovation, restoration, transformation and maintenance. Restoration and transformation are grouped together with renovation. Restoration is the same as renovation only that its authentic characteristics are preserved. Transformation is the change in the building's function. The main difference between new construction and renovation is that new construction involves shell construction. Based on the interviews it is concluded that SMEs are mostly into renovation construction projects and not into new construction projects. Consequently, logistics solutions must focus mostly on renovation projects.

2. *What are the current logistics structures for small-scale construction projects?*

Semi-structured interviews were mostly used to answer this subquestion together with a literature review. The interview respondents are stakeholders that are part of construction logistics. These

interviewed stakeholders are contractors, wholesalers, transporters and a municipality. The logistics structure of a construction project defines what transport movements are present. The vehicles used in construction logistics is the start of defining the logistics structures.

The first step in defining the logistics structures is to know which vehicles are used. The vehicles used for renovation projects are mostly delivery vans, box trucks and loader crane trucks. Occasionally, tractors and heavy trucks are used. New construction use dump trucks, concrete mixers and the same vehicles as renovation projects. Electric delivery vans are uncommon in the construction sector because of the high purchase price, range and dependence on the charging infrastructure network. Electric trucks are even more uncommon cause of the same reasons as for delivery vans. The prediction is that electric trucks will become competitive from 2028. ZE vehicles are not 100% ZE because electric vehicles still emit particulate matter (PM). The ZE zones have as main goal to decrease CO_2 emissions because that contributes to climate change.

The second step is to identify the cause of the vehicles' transport movements. There are three types of transport movements: material transport, personnel transport and equipment transport. Construction material transport can be distinguished into six construction flow types: concrete, shell construction large, shell construction load carriers, bulk, completion construction and heavy equipment. Completion construction flows are either large or small parts. Renovation projects' material logistics only involves completion construction. Material transport also consists of waste transport. The material supply is either delivered or picked up. The smaller a project is, the larger the share of pick-up deliveries will be. Subcontractors pick up more than main contractors because of their lack of planning. A wholesaler's dataset based on customers' orders shows that the further away the wholesaler's establishment is from the construction site, the more frequent orders will be delivered by the wholesaler. This implies that contractors are able to plan if necessary, which later on in the research is confirmed by a contractor. Personnel transport is the transport movement of contractors and subcontractors to and from the construction site. The equipment transport is the contractors' tools or heavy equipment. The larger a renovation project becomes, the more heavy equipment is needed. Nevertheless, small-scale construction projects have a limited amount of heavy equipment thus it is less important to find logistics solutions for heavy equipment.

3. *How do the objectives and roles of the various stakeholders involved affect the transport movements in construction logistics?*

The semi-structured interviews have been used as input for a stakeholder analysis to understand the objectives and roles of the stakeholders. The stakeholder analysis resulted in three matrices: a power-interest matrix, an influence-impact matrix and a stakeholder engagement matrix.

The key players in the problem situation are the subcontractors, suppliers, main contractors and transporters based on the power-interest and influence-impact matrices. Currently, the contractors are the problem owner; both the main contractors as subcontractors. This is because the ZE zones will first ban passenger vehicles and delivery vans which they use and because they are responsible for most of the transport movements of small-scale construction projects. The wholesalers and transporters will become the problem owner after 2025 because from that moment the contractors already need to have found solutions to arrive at the construction site within urban areas. The main problem found from the matrices is that subcontractors have low interest and influence whereas they are crucial to reduce the number of transport movements. The supply chain does not have a chain director and does not need one. However, main contractors must take a leading role supported by

suppliers, transporters and municipalities. Collaborations with each other are necessary to make the stakeholders more supportive in adopting logistics solutions.

4. *What are feasible logistics solutions to generate transport efficiency and sustainability?*

The interviews have been used to discuss the contractors', wholesalers' and transporters' perceptions of logistics solutions. Their experience on applied logistics solutions and their expectation of the future regarding the ZE zones show that there are opportunities for logistics solutions provided that requirements are necessary that make the solutions feasible. The solutions have been allocated over micro, small and medium renovation projects and new construction and over the type of transport movement (personnel, material, tools, heavy equipment). The solutions have been analyzed on which requirements (Table 13, Table 14, Table 15, Table 16) are necessary to make the solution feasible and what are the costs and benefits (Table 17) that the solution will deliver.

The feasible logistics for micro renovation projects are shown in Figure 2. The solutions for personnel and tools transport have many similarities because construction projects' personnel usually take their own tools with them in their vehicle to the construction site. The attachment of personnel and their tools has been found as a large problem. For example, public transport is not possible without tools are being provided at the construction site because contractors cannot take their tools in public transport. Furthermore, personnel and tools are separated on freelancers and SME personnel. SME personnel are the main contractors' personnel whereas freelancers are the hired subcontractors who are mostly freelancers. These two types of contractors have different roles within construction logistics. Carpooling is not possible for subcontractors because they have to go to multiple locations to work in one day for micro renovation projects.

The material transport solutions for micro renovation projects were difficult to find because the projects are very small and contractors often pick up the materials themselves. A very important requirement is that contractors improve the planning of work and procurement in order to let all the materials be delivered. There are three logistics solutions for the material supply (microhub, mobile hub, combining with other sectors) and one for the material return flow of waste (smart return).

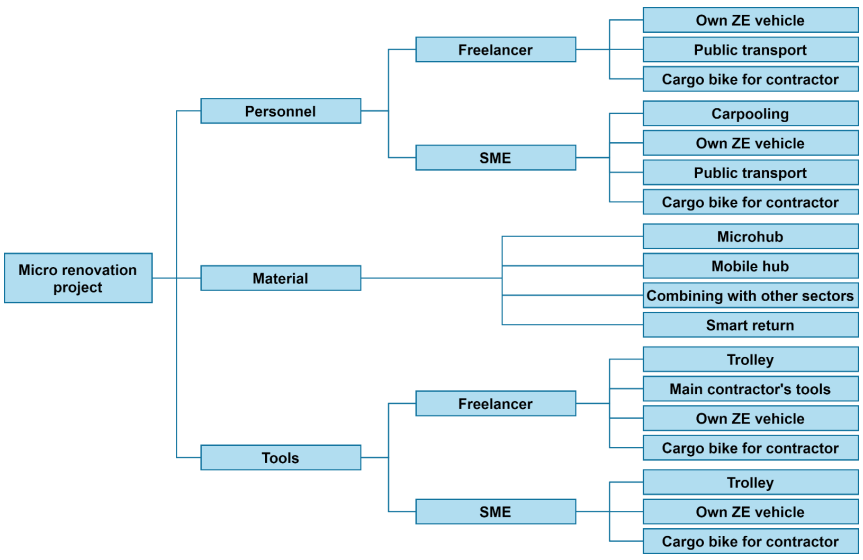

Figure 2: Overview of feasible logistics solutions for micro renovation projects

The feasible logistics solutions for small renovation projects (shown in Figure 3) have overlap with micro renovation projects. However, there are several adjustments due to the logistics characteristics' differences.

Personnel transport logistics solutions are now the same for freelancers and SME personnel. Carpooling was not possible for micro renovation projects because the contractors have multiple jobs for one day. Now, for small (and medium) renovation projects it is possible because these projects are larger and thus they are working at the construction site for an entire day. The same holds for a shuttle bus which was not possible for micro renovation projects because contractors can remain at the location for the entire day and do not need to travel in between.

There are nine material logistics solutions found for small renovation projects where three are the same as for micro renovation projects (mobile hub, combining with other sectors, smart return). The others are now feasible because the quantity of materials is now increased significantly.

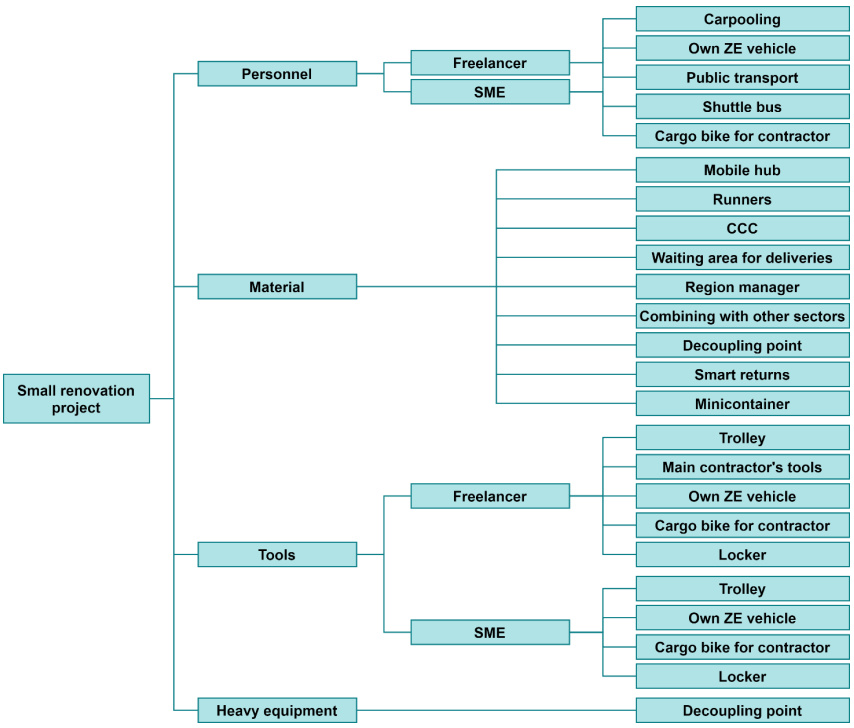

Figure 3: Overview of feasible logistics solutions for small renovation projects

The logistics solutions for medium renovation projects (Figure 4) are very similar to the solutions for small renovation projects. The only added solutions are for materials which are transport over water, building tickets and prefab. This shows that more solutions will be possible the larger a project becomes.

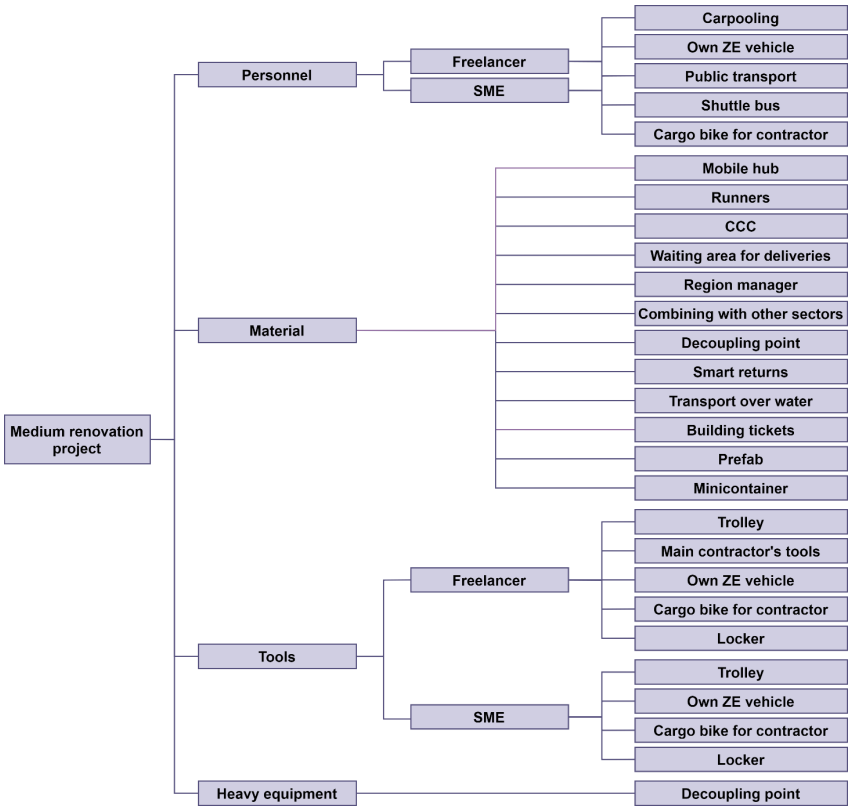

Figure 4: Overview of feasible logistics solutions for medium renovation projects

All the logistics solutions that can be applied to medium renovation projects can also be applied to new construction projects. The only added logistics solution is BIM (building information model). New construction projects' logistics solutions are less important within this thesis project because SMEs mostly execute renovation projects.

Logistics solutions for heavy equipment are difficult to find. The only found solution is decoupling point. The same holds for the transport of waste where only smart return has been found as a feasible logistics solution. This shows that the transition to ZE is not always achievable for specific transport movements. Other transport movements that are difficult to apply logistics solutions on are concrete mixer, prefab, heavy equipment and loader crane truck.

5. *How can the relevant stakeholders be informed about the urgency of the problem and the feasible logistics solutions for small-scale construction projects?*

The found allocation of logistics solutions needs to be communicated to the stakeholders in such a way to address the urgency and to share the found feasible logistics solutions. A product in the form of an instruction guide has been designed to share the findings in this thesis project to the stakeholders. This booklet can be found in 8.4 Instruction guide. The basic design cycle has been adapted for the development of this product (see Figure 1). Functional and non-functional requirements have been derived from the analysis step of the first three subquestions that have been used for the synthesis of the product. Furthermore, the product must have incorporated design principles to make the guide as effective as possible. After the synthesis, a contractor validated the product's design and confirmed that this is a good way to communicate the problem and feasible logistics solutions to the respective stakeholders. Also after the synthesis, evaluations took place to improve the product's design.

The instruction guide starts with the urgency of the problem and the definition of small-scale construction projects. Next, the guide is explained on how it should be used. Then, an overview of the logistics solutions and a timeline of when the solutions must be started with is shown. Lastly, the logistics solutions are explained, which requirements need to be present and what costs and benefits the solutions deliver.

Conclusion

The logistics solutions that fit the requirements of small-scale construction projects in urban areas are grouped on micro, small and medium construction projects and described in the answer of the fourth subquestion. The purpose of minimizing transport movements and emissions was used as a design requirement to find the logistics solutions that have led to a product to communicate the findings in this thesis project to the relevant stakeholders (contractors, wholesalers, municipalities, transporters). With this product, the awareness will be raised regarding the upcoming ZE zones and the feasible logistics solutions are shared so that they know what the solutions are, with whom they need to collaborate with and when they need to start with the organization of a solution.

To conclude, this thesis project shows where the opportunities lie to reduce the emissions in urban areas caused by small-scale construction projects' logistics. The costs and benefits of the logistics solutions need to be known for the stakeholders. Future research should analyze the impacts of the proposed feasible logistics solutions to quantify the costs and benefits. The stakeholder analysis and semi-constructed interviews resulted in that the stakeholders are still too passive and nobody knows who should take the lead. The upcoming ZE zones will make an impact and initiate a move that makes the traditional construction sector less traditional. Regulations from higher up are not always appreciated but will be adhered to if feasible.

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LIST OF ABBREVIATIONS

3PL	Third party logistics
4PL	Fourth party logistics
BIM	Building information model
BLVC	English: Accessibility, quality of life, safety and communication
CO_2	Carbon dioxide
CO	Carbon monoxide
CCC	Construction consolidation center
dB	Decibel
DC	Distribution center
GDSM	Group decision support method
MCA	Multi-criteria analysis
MCDM	Multi-criteria decision-making
NO_x	Nitrogen oxides
NEN	English: Dutch standard
NGO	Non-governmental organization
SME	Small and medium sized enterprise
SUCCESS	Sustainable consolidation centers for construction
TNO	English: Applied natural science research
TPL	Third party logistics
UAV	English: Uniform administrative conditions
UCC	Urban consolidation center
VCA	English: Safety, health, environment checklist contractors
VOL-VCA	English: Safety for operational supervisor – safety, health, environment checklist contractors
ZE	Zero-Emission

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CHAPTER 1: INTRODUCTION

In this first chapter, the purpose and the setup of this thesis project are discussed. The chapter starts with the current situation and why research is necessary. Afterwards, the scope is narrowed down that is used to define the main research question and its accompanied subquestions. Lastly, an outline of the report will be given.

1.1 PROBLEM STATEMENT

The world is facing climate change which has severe impacts on extreme weather events, biodiversity and rising seas. Greenhouse gas emissions need to be reduced to counteract climate change. Climate change causes severe consequences such as extreme weather events, rising sea level, risks for human health, costs for society and economy and loss of biodiversity (European Commission, n.d.). That is the reason why the Paris agreement has been signed. The Dutch climate agreement (concluded in June 2019) has been signed as a result of the Paris Agreement (2015) to combat climate change. The main goal of the Dutch climate agreement is to reduce greenhouse gas emissions by 49% by 2030 compared to 1990 (Overheid, 2019).

The 30 to 40 largest cities in the Netherlands have determined medium-large Zero-Emission (ZE) zones to take part in the Green Deal Zero-Emission City Logistics that will act upon 2025 that presumably leads to a reduction of 1.0 Mton CO_2. Out of all the traffic in cities, 30% is construction related (Beerda, 2019). A total of 20,000 trucks and 200,000 delivery vans enter the cities daily (De Bes, et al., 2018). Almost all vehicles need to take part in the green deal but there is an exception which is a transitional arrangement for trucks. that they can use trucks with emissions until the start of 2030 only if the European Emission standard is Euro VI. This is the most recent emission standard that is 90% cleaner than its precursor Euro V (Dijkhuizen, 2013). The transitional agreement states that Euro VI trucks older than five years and Euro VI tractors older than eight years are banned (SPES, 2019). The focus of the Dutch climate agreement lies in inner cities and that is exactly where the growth of construction activities takes place (Van der Meer, 2019). Moreover, the logistics costs weigh heavily for the construction sector. The value of the cargo is relatively low when compared to other sectors. This implies that an increase in logistics costs has a high impact on the total construction costs.

The ZE zones mitigate emissions of CO_2, NO_x and particulate matter. The gasses CO_2 and NO_x are greenhouse gasses and contribute to global warming. Particulate matter and NO_x are harmful to health and causing smog and are therefore unwanted in urban areas. The particulate matter comes partly out of vehicle exhausts but also from wear of tires so a phase-out of fossil fuel vehicles will not lead to a complete ZE zone. No emissions in the city center improve the quality of life, its attractiveness and the accessibility. This is especially relevant due to the increasing inhabitants of urban areas worldwide caused by urbanization. Factors that lead to a better quality of life are improved air quality and safety and less noise. Additionally, inefficiently managed construction logistics leads to economic losses and delays of projects.

Companies associated with this construction transport need to find innovative logistics solutions for the ZE zones because construction always needs to take place in these zones. In addition, the space to store materials on construction sites is limited in these zones often referred to as construction on a postage stamp. Therefore, logistics influences construction's efficiency. Recent years, most of the

attention has been paid to urban freight transport in general and not to the construction sector's supply chain in particular. Urban freight transport includes retail, food and home deliveries besides construction. The construction sector is responsible for a high number of transport movements with heavy vehicles and therefore a problem that requires more attention.

Next to the ZE zones, the Dutch government is working on an emergency plan in the construction sector to reduce the emissions of nitrogen (NOS, 2019). These emissions are being caused by operating heavy machines on the construction site but also by trucks and vans to transport materials, equipment and personnel to the site. The construction sector has the lowest quarterly growth in four years despite the enormous demand for new residences and offices nowadays where chief economist Peter Hein van Mulligen calls this situation a paradox (Eg & De Jong, 2020). The regulations demand a structural modification of the construction industry because they cannot handle it yet. The ZE zones are probably a too ambitious plan and Bouwend Nederland, a branch organization for enterprises in the construction and infrastructure sector, calls it unrealistic and counterproductive (Walinga, 2012). When heavy prefab (prefabricated construction parts) elements are disabled to transport because of the regulation, constructors and architects will traditionally design their construction by assembling at the site. That will lead to an increase in transport movements and therefore emissions. However, the ZE zones regulation sets a motion that the construction sector critically thinks about and reshapes its logistics. Supply of electric trucks is needed to meet the need of the ZE zones. However, at this moment less than 0.1% of the trucks in the Netherlands are electric (Nieuwenbroek, 2019).

The past decade, research about construction logistics has been carried out by research organization TNO (English: Applied Scientific Research). This was even before the climate agreements with a goal to save on logistics costs and construction time, to improve the flow, enhance safety and decrease the noise for the environment. Their mission is to strengthen companies and the well-being of society with knowledge derived from their research. The construction logistics' improvement is being addressed on European level by the CIVITAS initiative that strives for cleaner and better transport for cities. A part of this initiative is the Horizon 2020 project SUstainable Consolidation CentrES for conStruction (SUCCESS). Green and efficient solutions regarding construction supply chain in urban areas are explored, found and tested within this project with a focus on consolidation centers.

The upcoming ZE zones are present more quickly than most people think. Logistics solutions should be tested as soon as possible to determine the difference in costs and benefits with ordinary logistics. The information that is gathered from testing such logistics solutions can afterwards be used to see if the costs can be reduced or the benefits increased to make them more attractive. Larger contractors have resources for research and development and recently started testing logistics solutions. Small and medium-sized enterprises (SMEs) do not have those resources and do have a large share in construction within urban areas.

The problem situation described above can be summarized in the following problem statement:

There is a lack of knowledge about how to minimize transport movements and emissions in small-scale construction projects and a lack of awareness about the upcoming ZE zones among the stakeholders in the construction sector.

That problem statement will be analyzed and solutions will be proposed to confront the problem statement with the main research question:

Which logistics solutions fit the requirements of small-scale construction projects in urban areas with the purpose of minimizing transport movements and emissions, that can be adopted by the relevant stakeholders?

1.2 RELEVANCE OF RESEARCH

This thesis project is part of the master's degree program Engineering and Policy Analysis (EPA), where the two characteristics, multi-actor perspective and societal relevance, are the focus of the program. The construction logistics is composed out of many stakeholders that require an intensive cooperation making it a multi-actor system. The societal relevance is derived from the desired output of improving construction logistics that affects the well-being of society with better air quality, improved safety and less noise. Contributing fact to societal relevance is urbanization. The majority of the world's population is living in urban areas and that proportion is even increasing from 55% in 2018 to an expected 68% by 2050 making it an urgent and timely topic (United Nations, 2018). The Horizon 2020 project SUCCESS shows that this is not a national but an international problem. However, there are no international links in construction logistics towards the construction site. Therefore, research focused on the Netherlands only has a direct impact.

The core content of the EPA program is analyzing and solving grand challenges. The grand challenges applied in this problem situation are focused on energy, health and safety. Firstly, the main goal of the climate agreement is to mitigate greenhouse gas emissions which is in this case to have ZE in urban areas that demands a change towards sustainable alternatives of vehicles. Secondly, ZE in urban areas results in cleaner air that improves people's health. Lastly, fewer transport movements result in less danger and improved safety. Furthermore, the intensive cooperation between the stakeholders demands an understanding of the decision-making process. All the characteristics described above leads to that this problem is a perfect fit and relevant to the EPA program.

1.3 SCOPE AND DELIVERABLE

The literature review and discussions with fellow researchers have led to a knowledge gap for which research is required. Limited research is conducted on small and medium-sized projects because most of the research is about large-sized projects. At TNO there is some, but very limited, information available about small and medium-sized projects relevant for this thesis project. These small-scale (small and medium sized) projects are mostly executed by SMEs instead of the large construction firms. Hence, more research is needed to identify logistics solutions for smaller projects to improve efficiency and sustainability in logistics for SMEs. Large projects with a large enterprise as the main contractor can hire subcontractors classified as SME and the same holds for freelancers. These projects are left out of the scope. Freelancers can be hired by SMEs as subcontractors. These projects are inside the scope. The construction enterprises and their projects are visualized in Figure 5. The large projects are left out of the scope. The knowledge gap is still hard to define without reviewing existing literature. Hence, a literature review will be applied. This review is added in Appendix I.

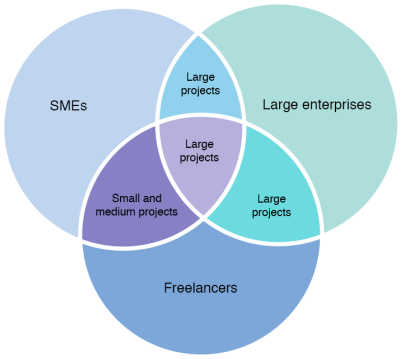


Figure 5: Construction enterprises and the projects they execute together

A first exploration of the stakeholders active in construction logistics has been made with the literature review. The supply chain is composed of multiple stakeholders with different objectives and roles. It is still unknown what these are and a stakeholder analysis is therefore required for understanding. The survey conducted by Akintoye et al. (2000) shows that stakeholders identify that supply chain management is important. Aljohani and Thompson (2019) mention that partnering of stakeholders requires an analysis of that multi-stakeholder situation. These two papers suggest a stakeholder analysis is necessary to improve construction logistics and for that reason this thesis project has made such an analysis. This analysis is conducted in this thesis project and conclusions of the analysis are given in 5.5 Conclusions on objectives and roles of stakeholders.

The two ways of delivering transport, single-drop and multi-drop, are an important aspect within logistics. A single-drop trip is unfavorable and should be transformed into a multi-drop trip. That will lead to a higher load factor and fewer transport movements. There is a lack of knowledge in which logistics solutions can be applied to small-scale construction projects to decrease the number of transport movements. There is no list of criteria defined to evaluate the logistics initiatives (Awasthi & Chauhan, 2012). Research is needed to come to that list of criteria. These requirements and the lack of knowledge to decrease the number of transport movements will be given at the end of this thesis project in 7.2.1 Micro renovation projects, 7.2.2 Small renovation projects, 7.2.3 Medium renovation projects and 7.2.4 New construction projects.

All construction logistics solutions found (see Table 20 in Appendix II) in prior research were analyzed on large-sized construction projects. An evaluation of these logistics solutions is required to know whether those solutions can also be applied in small-scale construction projects. Furthermore, an analysis of small-scale construction projects' logistics has not been executed before and is necessary to evaluate the problems those projects have in their logistics and to come to a list of feasible logistics solutions.

To conclude, research on logistics solutions applied on small-scale construction projects in urban areas has not been conducted before. As described in 1.3 Scope and deliverable, the focus of this thesis project lies in construction projects executed by SMEs because they represent many construction projects in urban areas. This thesis project provides how these construction projects and their logistics are set up (Chapter 3: Small-scale construction projects' characteristics and Chapter 4: Construction logistics' characteristics) and which logistics solutions are feasible (Chapter 7: Feasible logistics solutions). The deliverable of this thesis project is a product that is designed to communicate the findings to stimulate stakeholders to adapt the found logistics solutions (Chapter 8: Product:

Instruction guide). This contributes to the lack of academic knowledge about SMEs' construction logistics projects in urban areas.

1.4 OUTLINE RESEARCH REPORT

The aim of the report is to find solutions to the answers to the main research question and the subquestions by using a mix of methods. This thesis project will continue with a description of the research approach and applied methods in Chapter 2: Thesis project methodology. The main research question and accompanied subquestions above are explained by which methods they will be answered. Each chapter in Chapter 3: Small-scale construction projects' characteristics, Chapter 4: Construction logistics' characteristics, Chapter 5: Stakeholders' objectives and roles, Chapter 7: Feasible logistics solutions and Chapter 8: Product: Instruction guide will answer one subquestion. Chapter 3: Small-scale construction projects' characteristics will define what small-scale construction projects are. Chapter 4: Construction logistics' characteristics continues with the defined small-scale construction projects and defines how the logistics of these projects are organized. Chapter 5: Stakeholders' objectives and roles analyzes the stakeholders in small-scale construction on their resources and roles in the supply chain. Chapter 7: Feasible logistics solutions combines the found design requirements for logistics solutions in Chapter 3: Small-scale construction projects' characteristics, Chapter 4: Construction logistics' characteristics and Chapter 5: Stakeholders' objectives and roles to propose a list of feasible logistics solutions. Chapter 8: Product: Instruction guide combines the found information with the design requirements made during the report in the form of an instruction guide such that the urgency of the problem and feasible logistics solutions can be communicated effectively. Lastly, the conclusions are given in Chapter 9: Conclusions, discussion and recommendations.

CHAPTER 2: THESIS PROJECT METHODOLOGY

This chapter will present the thesis project's objective, the research questions in how to reach that thesis project's objective, the research approach and the applied methodology to answer the research questions. This will be summarized in the research flow diagram at the end of this chapter.

2.1 THESIS PROJECT OBJECTIVE

The thesis project objective is to improve the logistics of the small-scale construction projects and to raise awareness about the upcoming ZE zones. Researchers identify that collaboration is necessary to improve the entire supply chain. A broad approach to analyze the entire chain is therefore an opportunity to discover potential collaborations. The time period of interest that is analyzed in this thesis project is from 2020 till 2030, which is in line with the introduction of ZE zones in the Dutch cities. In 2025 are the first restrictions of banned vehicles in the 30-40 largest municipalities with a transition period towards 2030.

The thesis project objective is divided into two parts. The first part is to understand and describe the current logistics structures of small-scale construction projects in the Netherlands. It needs to be known what the problems are that the relevant stakeholders are facing before suggestions can be made on how to solve them. Furthermore, the relationships between the stakeholders and what their role is in construction logistics is essential to understand how logistics solutions can make an impact. The second part is to provide a list of feasible logistics solutions that can be applied to the logistics structures found in the first part. The deliverable of this thesis project is a designed framework of feasible logistics solutions represented in a booklet to communicate the findings of this thesis project.

2.2 RESEARCH QUESTIONS

To contribute to the problem as described in 1.1 Problem statement a main research question is defined. The identified scope and knowledge gap have led to the main research question. A list of subquestions will be answered in this thesis project to answer the main research question.

Main research question:

Which logistics solutions fit the requirements of small-scale construction projects in urban areas with the purpose of minimizing transport movements and emissions, that can be adopted by the relevant stakeholders?

Subquestions:

- SQ1: What are the characteristics of small and medium sized projects executed by SMEs?
- SQ2: What are the current logistics structures for small-scale construction projects?
- SQ3: How do the objectives and roles of the various stakeholders involved affect the transport movements in construction logistics?
- SQ4: What are feasible logistics solutions to generate transport efficiency and sustainability?

- SQ5: How can the relevant stakeholders be informed about the urgency of the problem and the feasible logistics solutions for small-scale construction projects?

2.3 THESIS PROJECT APPROACH

The thesis project approach that is applied in the first three subquestions is an **inductive approach**. This approach collects data and develops theory on basis of the results of that data (Saunders, Lewis, & Thornhill, 2012) instead of formulating hypotheses and test them as used in a deductive approach. The goal is to get a better understanding of the nature of the problem and how stakeholders think about the problem.

The thesis project approach that is applied in the last two subquestions is a **deductive approach**. The result will be to develop a theory such that it is known where possibilities lie that stakeholders can adopt new innovative logistics to decrease the number of transport movements. An important characteristic of a deductive approach is to search for causal relationships between variables (Saunders, Lewis, & Thornhill, 2012). These relationships are the logistics characteristics that the small-scale construction projects have and how logistics solutions can be implemented to improve the logistics of those small-scale construction projects in terms of emissions and transport movements reduction. The logistics solutions are designed to fit them for small-scale construction projects. Hence, this deductive approach is a design approach.

The first part (subquestion 1, 2 and 3) of the thesis project is a **descriptive research** because it is necessary to have a clear picture of the phenomena present in small-scale construction logistics. Afterward, (subquestion 4 and 5) the purpose is to use the performed analysis in the first three subquestions to **design a framework**. The design of a framework is explained in detail with the use of the applied method explained in detail in the end of the next paragraph.

2.4 METHODS SELECTION

In this paragraph, the selected research methods are explained. Possible limitations and the desired outcomes of the methods are discussed. In this way, it is known what the output of a subquestion is, that can help to answer other subquestions and eventually the main research question.

The start of this thesis project is a **literature review**. Subquestion 1 (*What are the characteristics of small and medium sized projects executed by SMEs?*) is to understand more about the problem. Small and medium sized construction projects' characteristics can be determined with the information found in literature. However, the best way to know what small and medium sized projects are is by interviewing the stakeholders themselves with **semi-structured interviews**. The list of questions asked in these interviews can be found in Appendix III.

The same set up of methods as for subquestion 1 is used for subquestion 2 (*What are the current logistics structures for small-scale construction projects?*). A semi-structured interview has a list of themes and questions to be covered that may vary from interview to interview (Saunders, Lewis, & Thornhill, 2012). In these kinds of interviews, some questions in specific interviews may be omitted and the order of questions may also be varied. Semi-structured interviews lead the conversation into areas that previously would not have been considered thus into new information that can help to address the research question or objective.

Interviews go along with some limitations. Reliability is an area for concern while applying semi-structured interviews because there is a lack of standardization. Next to reliability are two types of biases. The first is interviewer bias where the tone, comments or non-verbal behavior can influence the answers of the respondents (Easterby-Smith, Thorpe, Jackson, & Lowe, 2008). Also, the way responses are interpreted by the interviewer can demonstrate bias. The second type is interviewee or respondent bias (this thesis project will use the definition respondent and not interviewee). The respondents may choose to not reveal or discuss something because it can lead to probing questions about sensitive information that the respondent does not wish or is not allowed to share. Problems can also arise because of the time-consuming requirements that lead to respondents not willing to participate in the interview. In this case, your collected data sample is biased. The purpose of these interviews is to understand the respondents' explanations and meanings. Hence, own thoughts need to be held back because the attention should lie on listening.

Subquestion 3 (*How do the objectives and roles of the various stakeholders involved affect the transport movements in construction logistics?*) is answered with a mix of methods. The stakeholders are interviewed with semi-structured interviews as an input for a stakeholder analysis. The **stakeholder analysis** will be used to identify all relevant stakeholders and their perceptions, resources and objectives. This method creates ideas for alternative strategies by mapping options and interests of different actors (Enserink, Hermans, Thissen, Koppenjan, & Bots, 2010).

The stakeholders' perceptions of logistics solutions obtained from the interviews and the problems found from the interviews are used to answer subquestion 4 (*What are feasible logistics solutions to generate transport efficiency and sustainability?*). A limitation of a stakeholder analysis is that it should be performed continuously because the stakeholders' power and objectives may change. The problem after the first four subquestions is how to convince and incentivize the stakeholders to choose for a different logistics structure than they are used to. The answer to this subquestion is the content of the product that is designed in the last subquestion which is the deliverable.

The last subquestion, subquestion 5 (*How can the relevant stakeholders be informed about the urgency of the problem and the feasible logistics solutions for small-scale construction projects?*), is the design of a product to create an environment based on knowledge generated in this thesis project that stakeholders are willing to switch over to a new logistics structure. The design of the framework is the deliverable's design that will be a **booklet**. This booklet is a strategic communication tool that describes the key steps necessary to deliver value. It is constructed for the key stakeholders. The product's design is discussed and validated with the problem owner.

The model used to design the product is the **basic design cycle** invented by Roozenburg and Eekels (1995). The reason why this model has been chosen is that it can be applied to all sorts of design problems including in this thesis project. This model consists out of five process steps: analysis, synthesis, simulation, evaluation and decision. There is a feedback loop from the decision step backward to the analysis and synthesis step to solve design errors. The basic design cycle is adjusted in this thesis project where the step simulation is replaced by a validation step and a loop is created between analysis, design requirements and evaluations. The adjusted basic design cycle is shown in Figure 6.

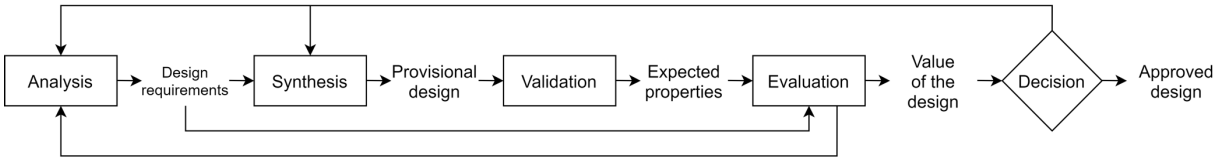


Figure 6: Adjusted basic design cycle based on Roozenburg and Eekels (1995)

Analysis: The first phase is the research on small-scale construction projects, its logistics and the roles of the various stakeholders involved. The analysis contributes to what the final design must be used for. This will result in design requirements. The design requirements from this process step are obtained in Chapter 1: Introduction, Chapter 3: Small-scale construction projects' characteristics, Chapter 4: Construction logistics' characteristics and Chapter 5: Stakeholders' objectives and roles and represented together in Chapter 6: Design requirements. The design requirements are either functional or non-functional. A functional design requirement is what the product must do and what product features must be implemented to enable the users to accomplish their tasks. A non-functional requirement describes how the design must work.

Synthesis: This phase starts in Chapter 7: Feasible logistics solutions where the feasible logistics solutions are applied to the requirements found in the analysis step. These solutions are evaluated separately before the second and final part of the synthesis takes place. Hence, the added loop between analysis, design requirements and evaluation. That final part is combining the information found and determining how to put it into a provisional design. Afterward, in 8.1 Goal and set-up the synthesis is completed before the product can be validated and evaluated.

Validation: A validation session with a contractor validated the provisional design. The validation can be found in 8.3 Process design cycle.

Evaluation: The evaluation is to establish the quality of the provisional design. The design will be compared with the design requirements and determined if these are met. The evaluation of the logistics solutions is done continuously with brainstorm sessions. The product's evaluation can be found in 8.5 Conclusions on instruction guide.

Decision: The decision is to continue with the design or to try again with a better design proposal. If the design is approved, the cycle has ended and the end product is generated. The final design can be found in 8.4 Instruction guide.

2.5 CONDUCTED INTERVIEWS

There were three meetings during this thesis project organized by branch organization for suppliers in construction logistics where various stakeholders of small-scale construction logistics were present. In one of these meetings, it became clear that Hogeschool Rotterdam (a lecturer and three students) and this thesis project were both carrying out research on the same problem but in a different way. Their research goal was to analyze if there were possibilities for sharing logistics. A decision was made to combine the interviews to prevent that respondents were going to give almost the same interview twice. Most of the interviews were conducted together with the students of Hogeschool Rotterdam. The interview respondents are given below in Table 1 and they are chosen to have a multi-actor perspective to hear the experiences from different types of stakeholders. The interview protocol with

questions used for the semi-structured interviews can be found in Appendix III. The contractors were all SME contractors and their size and type of construction work are shown in Table 2.

The list of questions (Appendix III) is made general because it was unknown before the interviews what the respondents' knowledge was about certain topics. During the interviews, more in depth-questions were therefore applied if a respondent knew more about problems in logistics or experiences with logistics solutions that led to new insights that were useful for this thesis project.

In this thesis project, there will be referred to the personal interviews made. However, the interviews will not be cited to keep the findings anonymous. Otherwise, this research could not be made public because there are competitors among the respondents which means that the information given in the interviews could be confidential.

Table 1: List of interview respondents (left blank for the public version)

Respondent	Stakeholder	Organization	Role	Experience
	Main contractor			
	Main contractor			
	Main contractor			
	Main contractor			
	Main contractor			
	CCC			
	Wholesaler			
	Wholesaler			
	Wholesaler			
	Transporter			
	Transporter			
	Municipality			

Table 2: Size and construction work of the interviewed SME contractors (left blank for the public version)

Number of employees	40	65	20	30	100
Yearly revenue (mln €)	10	70	15-25	12.5	43
Type of projects	Renovation Maintenance	New construction	Renovation New construction Maintenance	Renovation New construction	Renovation New construction Maintenance

2.6 RESEARCH FLOW DIAGRAM

The thesis project is split up into three different phases: research introduction, problem domain analysis and design of framework. The research introduction is always part of a thesis where the problem is defined, scope determined, the research question formulated and the research methods chosen (Chapter 1: Introduction and Chapter 2: Thesis project methodology). The second phase is the research methods applied to analyze the problem domain (Chapter 3: Small-scale construction projects' characteristics, Chapter 4: Construction logistics' characteristics and Chapter 5: Stakeholders' objectives and roles). The third and final phase is to design feasible logistics solutions (Chapter 7: Feasible logistics solutions) and to encourage stakeholders to apply these solutions with a design of a booklet (Chapter 8: Product: Instruction guide). Figure 7 shows the research flow diagram with three different phases.

The problem domain analysis consists of the first three subquestions (1, 2 and 3) that are used for the analysis process step of the basic design cycle. Subquestion 1 starts with an extensive literature review to understand the construction sector and its projects and ends with complementary knowledge derived from the semi-structured interviews. Subquestion 2 works the other way around and starts with semi-structured interviews to hear from the stakeholders themselves how small-scale construction projects' logistics operate. Afterward, literature has been reviewed to go more in-depth on the interviews' outcomes and to analyze where the problems lie within the logistics. This subquestion is essential to come up with a list of feasible logistics solutions that can be applied to small-scale construction projects. Subquestion 3 uses the semi-structured interviews as a foundation to understand the perceptions of the stakeholders after which a stakeholder analysis will be applied to come to new insights that will help to come to logistics solutions. Subquestions 1, 2 and 3 together will result in a list of design requirements for logistics solutions and a list of design requirements for the booklet.

The last two subquestions (4 and 5) are used for the synthesis, validation and evaluation steps of the basic design cycle. The list of design requirements for logistics solutions will be used in subquestion 4. The subquestion starts with the knowledge derived from literature review to know the logistics solutions found in prior research. The logistics solutions are discussed in the semi-structured interviews to understand what stakeholders think of the logistics solutions and what their experiences are with the logistics solutions. The results of subquestion 4 are the first part of the design of framework which is the product's content. Subquestion 5 is gathering all information derived in the previous four subquestions and merge that information into the product. A list of design requirements has been made what the product must adhere to (Chapter 6: Design requirements). Finally, the product's design has been approved and the thesis project has been completed.

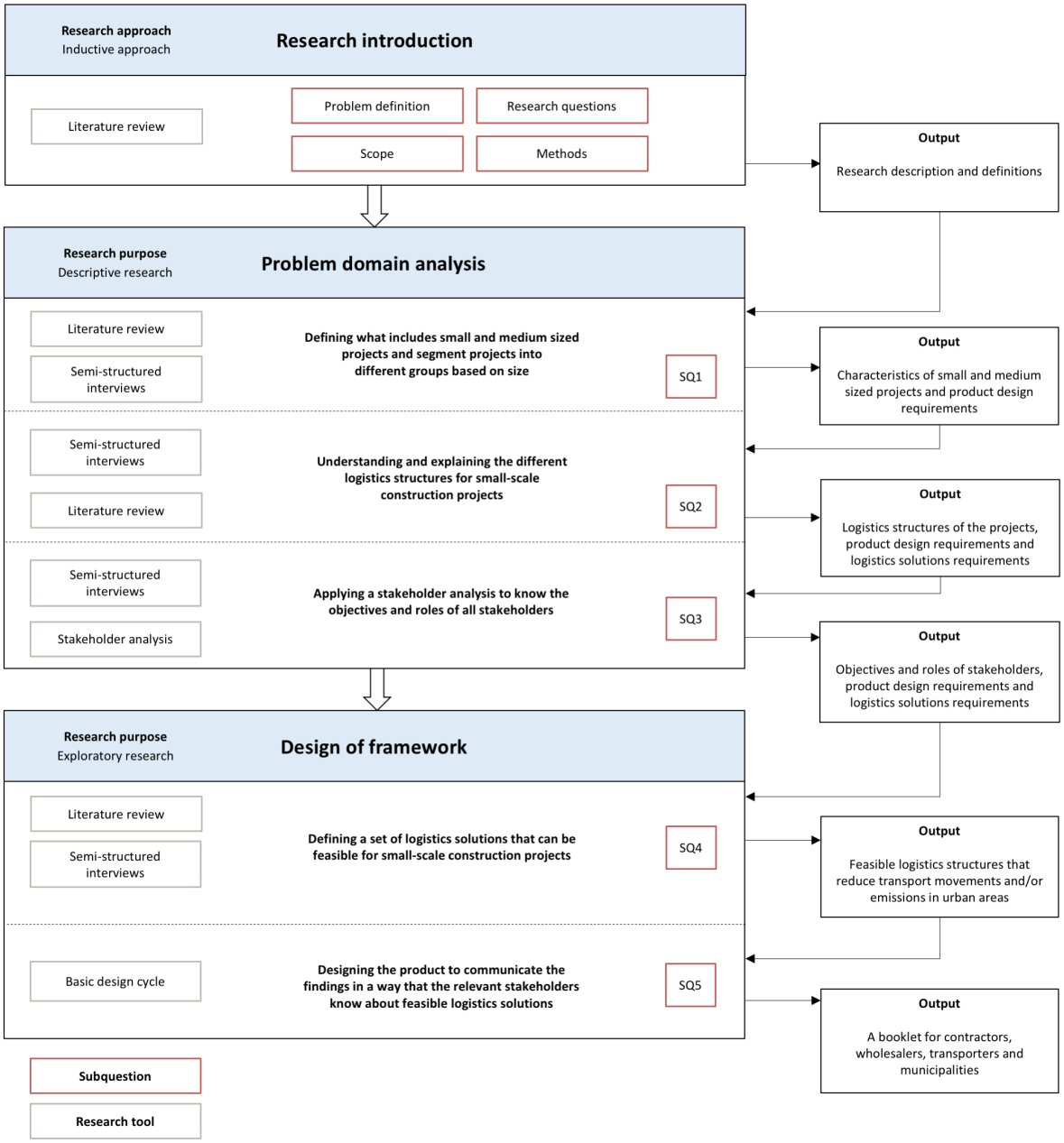


Figure 7: Research flow diagram

CHAPTER 3: SMALL-SCALE CONSTRUCTION PROJECTS' CHARACTERISTICS

SQ1: What are the characteristics of small and medium sized projects executed by SMEs?

The first part of this chapter is about the setup of SMEs and their share in the construction sector. Afterward, the type of construction projects and their typical activities are discussed. This chapter results in the answering of subquestion 1. The answer is given in what the characteristics of small-scale construction projects are to develop an understanding of these projects. Characteristics are the features of the project that makes it typical in the category small-scale. These characteristics are the first part of the analysis step of the basic design cycle.

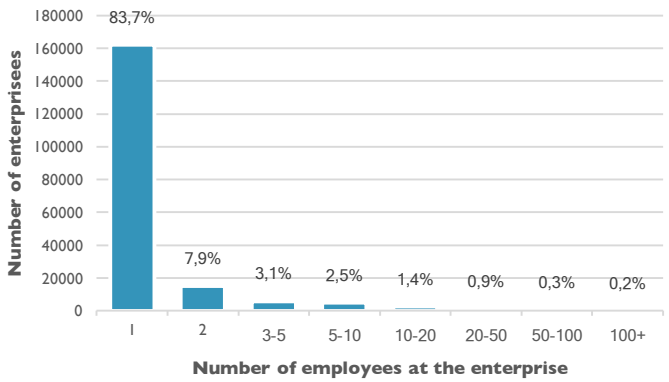
3.1 SMEs AND THEIR PROJECTS

The start of the research is the identification of the stakeholders of interest. The segment of interest is small and medium sized enterprises (SMEs) for the contractors. An enterprise belongs to a certain class if their annual account meets at least two criteria for two years from a row out of Table 3. In the Netherlands, there is a slightly different definition than for Europe but this can be seen as neglectable.

Table 3: Enterprise classes where two out of three criteria needs to be fulfilled for two years (Own table based on KVK (2020))

Criterion	Micro	Small	Medium	Large
Assets	< €350,000	€350,000 - €6 mln	€6 - €20 mln	> €20 mln
Net revenue	< €700,000	€700,000 - €12 mln	€12 - €40 mln	> €40 mln
Average number of employees	< 10	10 - 50	50 - 250	> 250

Often, construction projects are accepted by the main contractor and then outsourced to self-employed persons with expert skills classified as micro enterprises (Julen & Jak, 2020). The majority of the self-employed persons (which is a large part of the micro enterprises) do not expand their enterprise because of the financial risks of having personnel. SMEs are the backbone of Europe's economy and represent 99% of all businesses in the EU (European Commision, 2020). This also holds for the Netherlands where a total of 0.2% of all enterprises in the construction sector have more than 100 employees (CBS, 2020). The distribution of the number of employees in the enterprise is shown in Figure 8. Interesting is that 97.2% of all enterprises have less than 10 employees.



Number of employees in one enterprise	Number of enterprises
1	162,275
2	15,335
3-5	6,010
5-10	4,865
10-20	2,770
20-50	1,665
50-100	520
100+	375
Total	193,815

Figure 8: The number of enterprises and their number of employees in the construction sector (Own figure based on CBS (2020))

The objective of this thesis project is to help SME contractors with their logistics so that their emissions are decreased and to be prepared for the ZE zones. Another way to identify the logistics performed by SMEs is not based on the enterprises but on the size of the project in terms of area (m^2) or total construction costs. Osypchuk and Iwan (2019) made a classification of small, medium and large based on projects instead of enterprises. It could be that smaller subcontractors are working on large construction projects but in most cases, the main contractor would be a large enterprise. The total construction costs can also be a valid requirement to classify a project size. Luu and Sher (2006) came up with a different categorization based on construction costs. These two classifications are shown in Table 4.

Table 4: Construction projects classification based on area and costs (Own table based on Osypchuk & Iwan (2019) and Luu & Sher (2006))

Construction project size	Area Osypchuk & Iwan (m^2 gross floor area)	Costs Luu & Sher (€)
Micro	< 150	< 0.3 mln
Small	150 – 1,000	0.3 – 3 mln
Medium	1,000 – 10,000	3 – 20 mln
Large	> 10,000	> 20 mln

Construction costs of the different categories of projects are based on the type of building under construction. Brand et al. (2016) determined costs based on euro per square meter GFA. The costs of a project size for micro is less than €300,000. This amount of money for new construction fits perfectly for single the purchase of a private building. The area for such a building differs between cities. In Figure 9 the building area differs significantly between the twelve largest cities in the Netherlands that can be bought for €300,000. The area for micro projects can be concluded from this data. The ZE zones will apply to the 30-40 largest municipalities and are not all included in Figure 9. The trend in building areas is that Amsterdam is significantly more expensive than the rest and the smaller the city becomes the more the building areas are converging. The area for micro projects has defined below 150 m^2 because the other Green Deal cities are not represented. The graph shows a trend that it is reaching an equilibrium and therefore setting the limit of micro area size on 150 m^2 is a decent limit. However, the costs are for new construction and not for renovation costs. The 150 m^2 is therefore a soft limit. In this thesis project when referred to the area of a project, this represents the gross floor area (GFA). The GFA is the total area of the project. All areas that are part of the GFA are visualized in Figure 31 in Appendix IV.

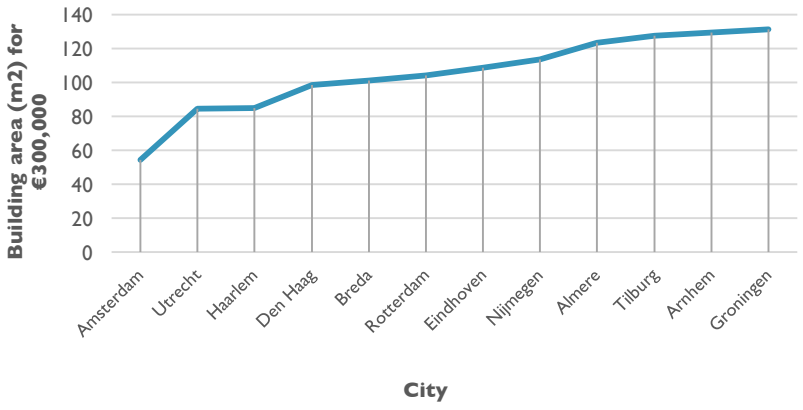


Figure 9: Building areas in the twelve largest cities in the Netherlands (Own figure based on Van den Hoven (2018))

The 150 m^2 limit is not the only soft limit. All limits of micro, small and medium sized construction projects are an indication and not hard limits. For example, a renovation project of a 200 m^2 building can be only installing a new bathroom whereas a renovation project of an 80 m^2 building can be renovating the entire building. The number of transport movements for the 80 m^2 building is therefore a lot higher than for the 200 m^2 building. Furthermore, a renovation project of 200 m^2 can also be a couple of apartments in one apartment block. These limits have been chosen to group them on specific logistics characteristics such as the number of projects a contractor has during a day.

Micro construction projects

In urban areas, there are many micro construction projects with an emphasis on renovation. Private house owners want to renovate their houses to improve comfort. The people responsible for construction work in micro construction projects are mainly freelancers and SME contractors. Furthermore, maintenance often takes place in urban areas and have low costs. These projects are most often executed by SME contractors where there is limited material transport and mostly personnel transport. A reference project is a renovation of a single residence in Den Bosch. The residence's GFA is 220 m^2. Total construction costs were €230,000. This is a large micro project because 220 m^2 GFA in urban areas is a large residence and the building was totally gutted and afterward renovated (Van Doorn, 2011).

Small construction projects

Typical small renovation projects are residential blocks or low terraced houses. The owners of these buildings are often housing corporations because they own multiple houses close to each other that are renovated simultaneously. SME contractors are the main contractors in these projects that outsource specific work to freelancers (or smaller SME contractors). A reference project is the renovation of fourteen monumental residences in Rotterdam owned by housing corporation Woonstad Rotterdam (Agentschap NL, 2010). The energy sustainability of the residences is improved. The total construction costs are €350,000. Renovation projects to improve energy sustainability is a trend that will be increasingly executed in the coming years.

Medium construction projects

This category is not only renovation but also transformation. Transformation can be considered as the same construction work as renovation because the shell construction is already present. There are some projects where transformation is of such a large size that it includes shell construction. These can be considered as new construction projects. The main contractor is often a larger SME contractor or a smaller large contractor. These projects contribute a significant amount of nuisance to the environment of the construction site because of its large size. A reference project is the renovation of 117 residences in Zaandam (Agentschap NL, Praktijkvoorbeelden Corporaties: Wibautstraat, woningcorporatie ZHV, Zaandam, 2012). The client of this project is a housing corporation that renovated the residences and improved energy sustainability with isolation and boilers. The total construction costs are €7,137,000 on which 24% is spent on energy-saving measures.

3.2 SHELL AND COMPLETION CONSTRUCTION

Construction operations can take place in the shell phase or at the completion phase. The shell phase is at the start of building something new whereas the completion phase finalizes that construction project. The shell phase is the raw construction and will be called shell construction (*Dutch: ruwbouw*) in the rest of this thesis project. The end product of the shell phase is that the building is wind- and waterproof. The completion phase comes afterward and needs to deliver the end product. The end

product is completed when the building is prepared for habitation. This completion phase construction will be called completion construction (*Dutch: afbouw*) for the rest of this thesis project. The building parts that are placed in these two phases are given in Table 5. The completion construction is needed to meet all requirements the residence must have such as comfort, sustainability and (fire) safety.

Table 5: The building parts of construction placed in shell and completion construction (Own table based on Baal (n.d.))

Shell construction	Completion construction
Foundation	Screed
Sewerage	Ceilings
Large part of the pipes	Kitchen
Load-bearing walls	Bathroom
Roof	Finishing walls
	Inner walls, inner doors, inside door frames,
	Stairs (not always)
	Electricity
	Finishing pipes
	Ventilation system
	Paintwork
	Tiling

There are different types of construction projects. These types are new construction, renovation, restoration, transformation and maintenance.

- New construction is construction projects of buildings that were not there before and are built from scratch.
- Renovation is construction projects of buildings that are adjusted to meet the requirements in terms of sustainability or safety but also for a modern application of use. Usually, the residents cannot remain in the building during renovation and need to be compensated for this disability. There is a trend in renovation that residences must remove the natural gas input and must only have electricity as an energy source. The first step is that 1.5 million residences must be made sustainable by 2030 done by removing the natural gas input (Overheid, 2019).
- Restoration is returning a building to its former state and is most commonly applied to historic buildings. Only traditional materials and techniques are used for restoration to preserve authentic characteristics.
- Transformation is construction projects when the function of the building changes. For example, this can be the adjustment of offices into an apartment building, hotel or student flat.
- Maintenance is construction projects which consist out of activities to preserve or to bring back the building into an acceptable condition.

There is a large difference between the use of materials between shell construction and completion construction. The difference in the use of materials has an impact on the different used transport. The completion phase building parts are composed of a large variety of materials. Logistics solutions must be generic enough to be applied to that large variety of projects and coherent materials.

3.3 CONSTRUCTION PROJECTS IN ROTTERDAM

The selected scope (see 1.3 Scope and deliverable) and the classification of projects (see 3.1 SMEs and their projects) combined leads to the definition of small and medium sized projects. The scope of interest (visualized in Figure 5) is the projects executed by SMEs that are not large in size because they might be a subcontractor of a large enterprise in a large project. The size is based on area size and construction costs shown in Table 4.

A dataset of building tasks requested at the municipality of Rotterdam is used to evaluate the found size of projects based on area. This dataset was provided by municipality Rotterdam and the number of requests was representative of the total number of projects in the year 2018 because the data was handed in that time period. Afterward, not all projects are requested yet. The majority of the projects are situated below 10,000 m^2 and less than 100 houses (see Figure 10). Most of the projects between 1,000 and 10,000 m^2 are below the 5,000 m^2. Not all construction projects are included in this dataset because small renovation projects do not require a planning permission and therefore not requested at the municipality. Regulations on whether a planning permission is required depend on the building area, if it is in the backyard area and how high the construction work will be (Ministerie van Infrastructuur en Milieu, 2017). Figure 10 has a closer look into the projects below 1,000 m^2 and between 1,000 and 10,000 m^2 in the two bottom graphs. There are not many projects above 10,000 m^2. This data shows that small-scale projects have a high impact on the number of transport movements and emissions in urban areas.

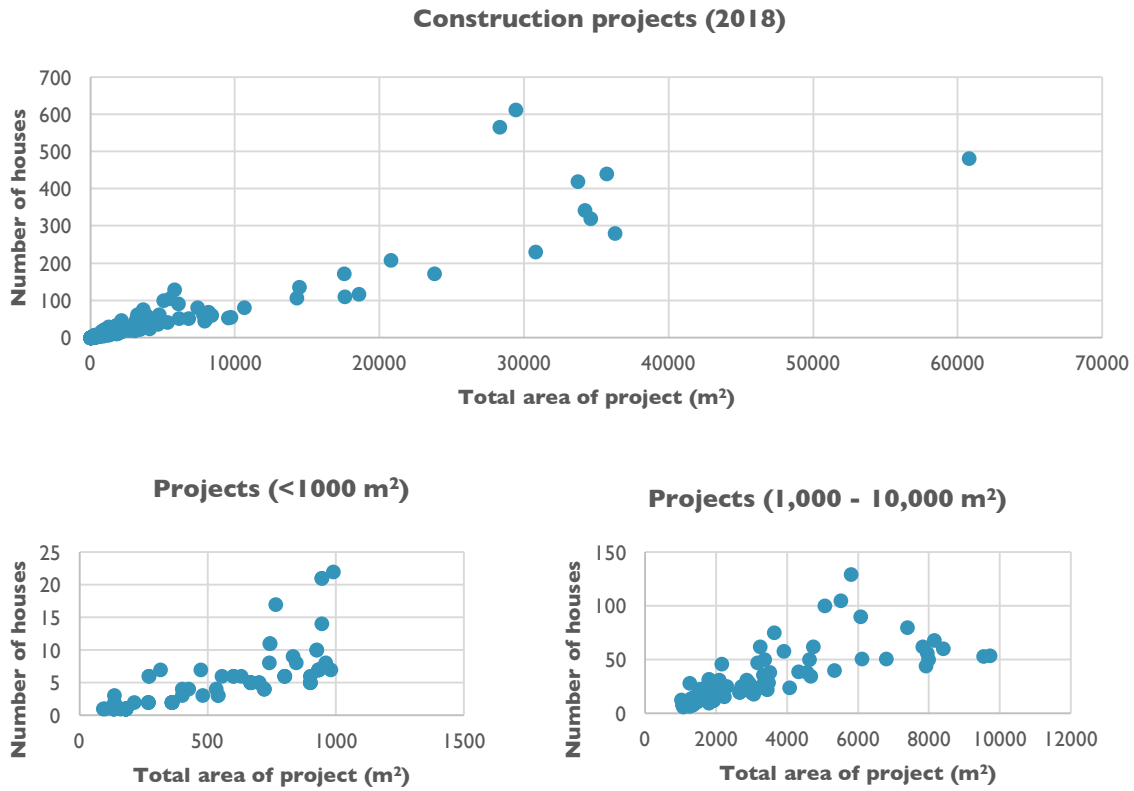


Figure 10: Building tasks requested at municipality Rotterdam in 2018 (Own figure based on anonymized dataset of building assignments in Rotterdam)

3.4 CONCLUSIONS ON CONSTRUCTION PROJECTS CHARACTERISTICS

What are the characteristics of small and medium sized projects executed by SMEs?

The characteristics of small and medium sized projects executed by SMEs are divergent and therefore difficult to form specific characteristics. The best way is to group the projects on area size and on total construction costs. Before this thesis project, only small and medium sized construction projects next

to large sized projects were considered. The literature review has resulted in a better definition that also includes micro sized construction projects. All these three construction project sizes together (micro, small and medium) will be considered small-scale projects in the rest of this thesis project. This classification helps to search for the characteristics of logistics and fitting logistics solutions.

SMEs are mostly into renovation projects and especially in urban areas. Municipality Rotterdam's data did not incorporate building assignments for private renovations (micro projects). However, in the interviews, it came up that this is still a large share in urban areas and solutions must be found for micro construction projects.

Now that it is known what the construction projects are, it must be known what logistics characteristics these projects have. There are differences based on construction project size. Chapter 4: Construction logistics' characteristics will analyze the classification of micro, small and medium with a focus on renovation projects because those projects are the most relevant for the problem situation.

Feasible logistics solutions requirements that were found in this chapter are:

- Micro logistics solutions must allow contractors to drive to multiple locations during the day. (Functional requirement)
- Logistics solutions must be generic to be applied to a large variety of projects and coherent materials. (Functional requirement)
- Logistics solutions must focus on freelancers and SMEs separately. (Non-functional requirement)

The booklet design requirements that were found in this chapter are:

- The booklet must separate logistics solutions on micro, small and medium sized construction projects. (Non-functional requirement)
- The booklet must separate renovation projects and new construction (Non-functional requirement)
- The booklet must focus mostly on renovation projects (Non-functional requirement)
- The booklet must show reference pictures of micro, small and medium sized construction projects to visualize the concept. (Non-functional requirement)

CHAPTER 4: CONSTRUCTION LOGISTICS' CHARACTERISTICS

SQ2: What are the current logistics structures for small-scale construction projects?

This chapter will discuss the logistics characteristics of small-scale construction projects that are described in the previous chapter. Firstly, the chapter starts by describing what vehicles are used in construction logistics. Secondly, a more in-depth analysis of the vehicles will be applied. Lastly, the transport movements are analyzed on what is transported. This is necessary to understand what logistics solutions can be applied to certain transport movements. This is the second step in the analysis of the design cycle.

4.1 VEHICLES USED IN CONSTRUCTION LOGISTICS

First, a classification of different vehicles is needed to describe the logistics characteristics of the construction sector. Every construction project needs different types of vehicles. Within different types of projects and material flows, a distinction can be made to what vehicles are used. The vehicle classification is also necessary to indicate which vehicles are banned to drive in urban areas from 2025 and from 2030. The transitional agreement states that Euro VI trucks older than five years are banned and Euro VI tractors older than eight years (SPES, 2019). Fossil fuel passenger cars and vehicles are all banned in urban areas from 2025.

A study conducted by TNO observed heavy vehicles on the Dutch highways (Kuiper & Ligterink, 2013). In this study, they have made a subdivision between trucks. This subdivision is necessary for some of the vehicles used in construction transport. The vehicles have been tested on three parts: vehicle detection system, axle load measuring system and identification system. Induction loops in the road surface measure the length of the vehicle and afterward the distances between individual axles and axle pressure on the individual axles are measured. Vehicles under seven meters have been disregarded as the study focused on freight traffic. The distribution of the measured freight traffic is visualized in Figure 11. The distribution is based on the load on the front axle and the distance between the first two axles. The categories are grouped and numbered in the black boxes. The colors represent the number of vehicles measured for that specific axle pressure and distance.

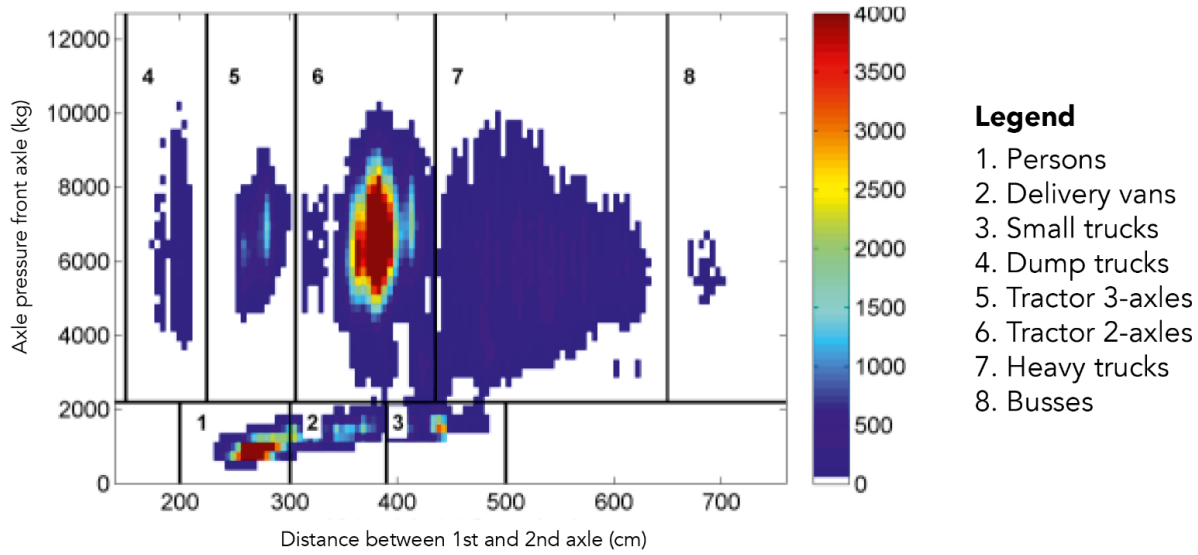


Figure 11: Distribution of freight traffic on Dutch highways (Kuiper & Ligterink, 2013)

In Figure 11 and thus in freight traffic, a distinction has been made between light and heavy freight traffic. The small trucks category is not clear what trucks these are according to the research. Possibly, these are delivery vans where the back of the truck is open. The dump trucks are heavy vehicles of the construction industry. The distance between the axles is relatively small because these vehicles transport large amounts of bulk. Categories 5 and 6 are the tractors that have either two or three axles. The large dark red spot in Figure 11 shows that the 2-axles tractors are the most common in heavy freight traffic. These tractors are used in construction mostly to transport heavy equipment or large construction parts by attaching a trailer. The 3-axles tractors have a double rear axle. Dependent on the size and weight of the heavy equipment and material the trailer with the necessary number of axles is chosen. Category 7 is the heavy trucks. There is a large variety of distance between the first and second axle. These heavy trucks only have two axles. The heavy trucks are split up into two different vehicle types used in construction logistics which are the box trucks and heavy trucks. Busses are not relevant for construction logistics.

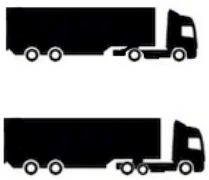
All construction logistics vehicles that use the road are shown and shortly described in Table 6 on what their transport is and in which type of construction they are present. There is no data available about the actual usage of vehicles in the construction sector so this analysis is based on the heavy transport traffic data of Kuiper and Ligterink (2013) and own insights gained during literature review and interviews.

There are specific vehicles that are used in construction logistics that can transport the materials from the vehicle on the desired location with a loader crane. This can either be outside or on a different height at a specific floor in the building. These vehicles can be used to directly transport the materials vertically without using a tower crane. The use of tower cranes in small-scale construction projects is only used in new construction and almost never in renovation construction. Furthermore, the materials delivered can be heavy and difficult to transport manually which makes the loader crane a useful tool.

The weight a vehicle is allowed to carry is essential in the construction sector. A wholesaler mentioned that they do not use delivery vans, they only use trucks. Empty delivery vans weigh on average 1,750 kg and their maximum load capacity is 3,500 kg including the vehicle's weight (Belastingdienst, 2020;

De Groot, et al., 2017). Heavy pallets are no option to transport by delivery vans because of the maximum load capacity. Next to trucks, tractors with trailers are used for suburban logistics. Tractors with trailers are therefore not used for completion construction materials but only used for heavy equipment and for large and/or heavy materials needed for shell construction.

Table 6: Vehicles used in construction logistics

Vehicle	Pictogram	Transport	Presence
Delivery van		Personnel, small materials such as boxes and tools.	Renovation, new construction
Box truck		Materials transport. Mostly completion construction.	Renovation, new construction
Heavy truck		Materials transport. Can transport longer materials that are more difficult for box trucks.	Mostly new construction, sometimes renovation (medium sized)
Loader crane truck		Materials to be transported on desired height. Pallets and other objects can be transported directly from the truck on the ground. Waste containers are also transported with loader crane trucks.	Renovation, new construction
Tractor 2-axles or 3-axles		Heavy materials transport for shell construction and heavy equipment transport. A 3-axles tractor is capable of heavier transport.	Mostly new construction, sometimes renovation (medium sized)
Dump truck		Bulk materials transport for shell construction.	New construction
Concrete mixer		Concrete transport.	New construction

Renovation transport vehicles are primarily delivery vans, box trucks and loader crane trucks. The heavy vehicles are used for new construction. The transition towards ZE is easier for delivery vans and box trucks used in renovation than for the heavy vehicles used in new construction. There are multiple logistics solutions applicable for delivery vans and box trucks that will be analyzed and discussed in Chapter 7: Feasible logistics solutions. Preferably, logistics solutions must apply to vehicles with a low load factor. Loader crane trucks' load factor is generally higher and therefore less urgent. These insights are further elaborated in 7.2.7 Difficult ZE implementation.

4.1.1 DELIVERY VANS FLEET ANALYSIS

Electric delivery vans are still in the introduction phase. The advantages of electric delivery vans are lower mileage costs, no CO_2 emissions and lower maintenance costs. The disadvantages are higher purchase price, the range and the dependence on the charging infrastructure network. The most sold electric and fossil fuel delivery vans with their purchase price are shown in Figure 12 and listed in Appendix V. The blue bars in the figure are fossil fuel delivery vans and the green bars are electric delivery vans. These purchase prices confirm that electric delivery vans are still too expensive.

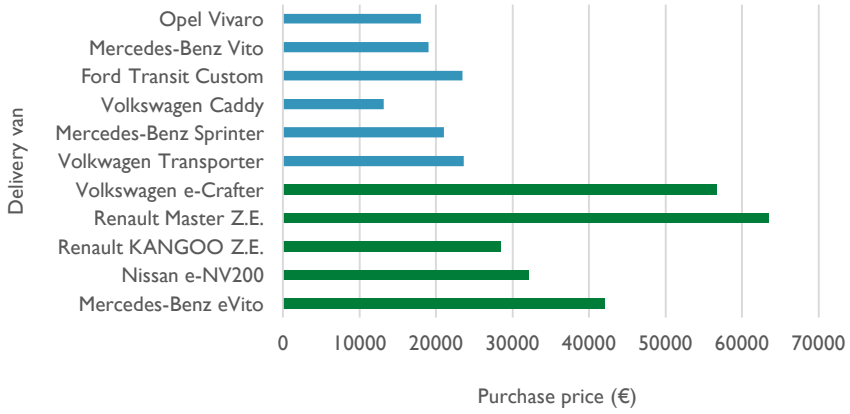


Figure 12: Most sold delivery vans (Own figure based on ANWB (2020) and Bestelauto (2020))

Furthermore, a critical criterion is the vehicle age. The histogram in Figure 13 indicates the age class of a delivery van fleet in 2016 according to De Groot et al. (2017). Delivery vans between 0 and 12 years old are strongly represented. The number of vehicles strongly decreases from 12 years old. The histogram visualizes each year as a bar until 25 years. All delivery vans are merged in one bar after 25 years and those delivery vans have a share of 3% in the delivery van fleet.

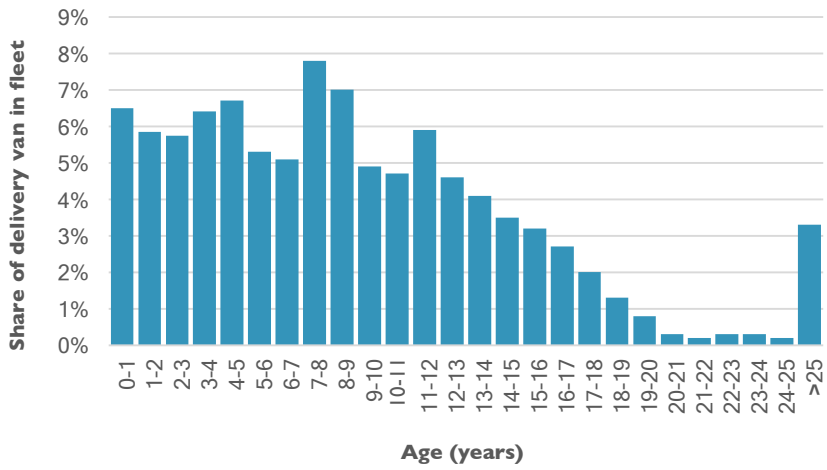


Figure 13: Delivery vans' age based on the entire Dutch delivery van fleet in 2016 ((De Groot, et al., 2017)

Approximately 11% of the delivery vans are not registered at a company. These are in general the older delivery vans. Therefore, all delivery vans older than 25 years are presumably not used by contractors. The data used for the histogram (Figure 13) contains all delivery vans and is not specified in the construction sector. The average delivery van age in the construction sector is 8 years whereas the total delivery vans' average age is 9 years. The number of employees in the company affects the delivery van's age. Figure 14 shows the delivery vans' age for the construction sector and all sectors combined by the number of employees in a company. The depreciation time of a delivery van decreases when the number of employees in the company increase. A freelancer's delivery van in construction has an average age of 9.5 years. The interviewed main contractors in this thesis project are all SMEs that have between 10 and 100 employees (see Table 1). Hence, their vehicles depreciate on average in 7 years.

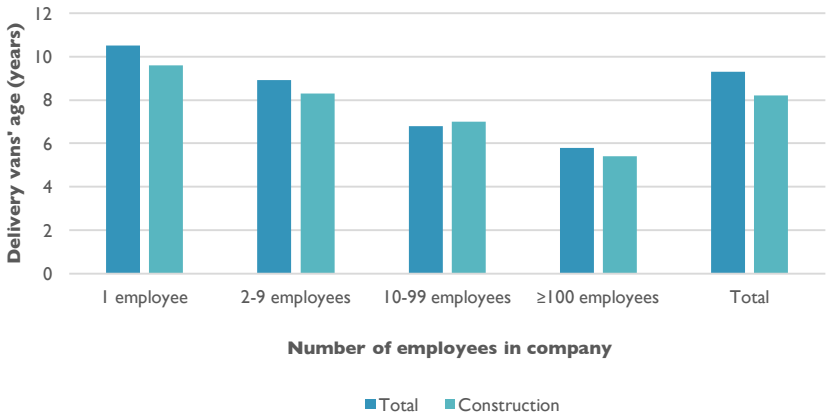


Figure 14: Delivery vans' age by company size in the construction sector and total (De Groot, et al., 2017)

The ZE zones will initiate from 2025. Problems will arise concerning the delivery vans' average age. The histogram (Figure 13) is based on data in 2016 and it is assumed that it is not largely changed in 2020. Already a large part of the delivery vans is purchased in the last couple of years that will still function optimal that cannot enter urban areas from 2025, assuming that the trend of the histogram has not changed significantly in the last four years. This problem is even larger for the freelancers than for the SME main contractors for three reasons. Freelancers use their delivery van on average 8.5 years instead of 7 years, the freelancers are more short-term oriented than SME main contractors and the SME main contractors have more financial resources to substitute part of their vehicle fleet to ZE than freelancers.

4.1.2 TRUCKS ZERO-EMISSION TRANSITION

Where electric passenger vehicles' sales have rapidly increased in the last decade and electric delivery vans are increasing since recent years, are the electric trucks in the introduction phase. At the end of 2019, there were only 94 electric trucks in the Netherlands (Veldhoven, 2019). A report by Luman (2019) went in-depth on the prospective situation of ZE trucks. In this report, the different alternatives for ZE trucks are analyzed and the battery-electric truck has been discussed in detail. The mentioned different alternatives are:

- Bio- or synthetic fuel
- Diesel-electric (hybrid)

- Battery-electric
- Hydrogen-electric

The bio- or synthetic fuel has high production costs and there is too much demand from other sectors which makes this alternative relatively expensive and thus less obvious. There are three different electric alternatives: hybrid, battery or hydrogen. The hybrid-electric can be used in such a way that the truck switches over to electric at the zone boundary. However, the hybrid technology is more expensive and is expected to reduce barely in price. The battery-electric truck is still too expensive at this moment. The price of European electric trucks is now around €300,000 which is significantly more than a Euro VI diesel truck that is around €85,000. There will be a regulation that the government provides subsidies of 40% of the additional costs of an electric truck's price (Van Gurp, 2019). The battery-electric engine has relatively high efficiency to move the truck thus the energy usage per kilometer is low. The hydrogen-electric truck is too expensive and there is a large waste of energy in the production. Battery-electric trucks are regarded as the most promising alternative due to the advantages of efficiency. Hydrogen-electric trucks are promising to use for long-distance transport. Battery-electric trucks have a range of 100-150 km, thus are only usable for urban and regional distribution.

The public loading infrastructure for electric trucks is largely unavailable. The normal loading stations are incapable to charge trucks because trucks need a stronger load speed. Moreover, the costs of a truck loading station are high. The purchase and set-up costs are around €318,000 for the most powerful charging station with a load speed of 350 kW. However, the energy costs are lower for electric trucks than for diesel truck and the maintenance costs are lower. The conclusion of Luman's report (2019) is that trucks will be competitive from 2028 if subsidies are included. The expected sales in Figure 15 show that the number of electric trucks is increasing. However, this is minimal compared to the total number of trucks. There are 140,000 heavy trucks in 2020 in the Netherlands (RDW, 2020). This makes the prediction of 3,500 trucks in 2030 only 2% of the entire truck vehicle fleet.

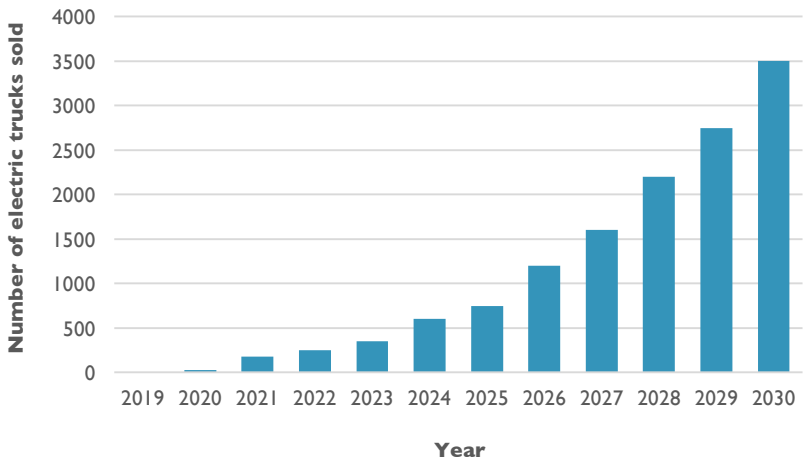


Figure 15: Expected sales heavy electric trucks (Luman, 2019)

The concrete mixer is a different type of vehicle. The concrete mixer is either a single truck or a tractor with a concrete mixer trailer. The concrete mixer trailer is powered separately from the tractor and can be decoupled. The advantage of concrete mixer trailers is that they are flexibly deployable. The rise of electric concrete mixers or concrete mixer trailers occurs slowly. The old diesel engines can be replaced by electric motors.

4.1.3 EMISSIONS CAUSED BY VEHICLES

The switch to electric vehicles does not imply that the vehicles are becoming completely ZE. Particulate matter (PM) is one of the vehicles' emissions that is linked to negative health effects. Governments incentivize the market to switch to electric vehicles. However, electric vehicles are not decreasing the levels of PM as much as expected. The total PM_{10} (particles less than 10 µm) emissions from electric vehicles are found equal to modern fossil fuel vehicles and the total $PM_{2.5}$ (particles less than 2.5 µm) emissions were only 1-3% lower for electric vehicles (Timmers & Achten, 2016). The reason is that the exhaust standards are improving continuously thus the PM emissions of internal combustion engine vehicles are low and decreasing. Furthermore, there is a positive relationship between the vehicle's weight and the vehicle's non-exhaust PM emissions. The heavier the vehicles become, the more non-exhaust PM they will emit. Non-exhaust PM emissions typically come from abrasive sources which are brake wear, tire wear and abrasion of the road surface (Thorpe & Harrison, 2008). It is difficult to identify and quantify the source for non-exhaust traffic particles because they interact with each other. The particles from the brakes or tires for example can deposit on the road surface that will add up to the road soils.

The European Commission has set regulations to restrict emissions from vehicles. This emission standard forces vehicle manufacturers to invest in developing cleaner-burning and more efficient engines (Van Oostvoorne, 2015). The standards are applied to either light or heavy-duty vehicles. The standards for light-duty vehicles are separated on diesel and petrol. And within this separation of diesel and petrol, the vehicles are grouped on passenger cars and three classes of light commercial vehicles based on weight. The most used vehicles in small-scale construction projects are delivery vans for personnel and box trucks (still heavy-duty) for material supply. These standards are represented in Table 7. Not all standards are given because they are almost similar and it is used as an indication. Chosen is for the middle weight class as an average for light-duty vehicles and there is chosen for diesel because most delivery vans have diesel engines. The entire vehicle is tested for light-duty vehicles and emissions are measured in grams per kilometer (g/km) and heavy-duty vehicles the engine is tested in relation to the engine power (g/kWh) (Lindqvist, 2012).

Table 7: EU emission standards for light-duty (Class II, diesel) vehicles and heavy-duty (diesel) engines (Own table based on (2019))

Euro level	Heavy/light-duty vehicle	Year of implementation	CO	NOx	PM
III	Heavy	2000	5.45 (g/kWh)	5.0 (g/kWh)	0.16 (g/kWh)
IV	Heavy	2005	4.0 (g/kWh)	3.5 (g/kWh)	0.03 (g/kWh)
V	Heavy	2008	4.0 (g/kWh)	2.0 (g/kWh)	0.03 (g/kWh)
VI	Heavy	2013	4.0 (g/kWh)	0.46 (g/kWh)	0.01 (g/kWh)
3	Light	2000	0.8 (g/km)	0.65 (g/km)	0.07 (g/km)
4	Light	2005	0.63 (g/km)	0.33 (g/km)	0.04 (g/km)
5	Light	2010	0.63 (g/km)	0.235 (g/km)	0.005 (g/km)
6	Light	2015	0.63 (g/km)	0.105 (g/km)	0.005 (g/km)

Trucks' NO_X emissions have decreased significantly in the last decades. The NO_X emissions of heavy-duty engines have decreased from 5 g/kWh for Euro III engines to 0.46 g/kWh for Euro VI engines (DieselNet, 2019). The CO emissions have stagnated at 4.0 g/kWh since Euro IV. The PM emissions are compared to the other emissions the lowest with only 0.005 g/km.

The CO_2 emissions cannot be addressed by a 'one-size-fits-all' policy and are therefore not included in the EU emission standards (ACEA, n.d.). The shape of the vehicle and the usage pattern is dependent on the emissions. The regulation on CO_2 is only applied recently on passenger cars and vans and does

not cover heavy-duty vehicles. Furthermore, the Euro standard is not required on a single vehicle but for the weighted performance of the entire vehicle fleet produced by a manufacturer in a year (Lindqvist, 2012). Therefore, CO_2 is not included in the emission standards table. The fleet average emissions targets 95 CO_2 g/km for passenger cars and 175 CO_2 g/km for light-duty vehicles (ICCT, n.d.) which is significantly more than the other emissions.

All urban freight traffic emissions cause direct human health risks. PM is linked to increased rates of premature death, CO displaces oxygen from the blood and can cause heart problems, NO_X can increase respiratory illnesses and CO_2 can cause inflammation, reduced cognitive performance and kidney and bone problems (AECC, 2020; Jacobson, et al., 2019). Electric vehicles have no emissions except PM. The amount of emitted PM, as can be seen from the emissions standards, is low compared to the other pollutants.

4.2 CONSTRUCTION FLOW TYPES

In the medium sized renovation classification, three case studies are present to determine the characteristics. The case studies are a new construction of multi-family houses that maintains its national monumental façade (5,000 m^2 GFA), a renovation of an office building (7,000 m^2 GFA) and a renovation with partly new construction of a hotel (82 rooms). These projects were already subjects for innovative logistics solutions and therefore their material flow has been monitored. The data from the projects differ and therefore not all the same information is known. However, conclusions for this category on their logistics structures can be made from these projects.

The national monument new construction categorized their material and heavy equipment flow chronologically on construction flow types. Each construction flow type has a list of materials with a dedicated load factor and number of transport movements. The average load factor is based on these construction flow types and calculated by dividing the load factor by the number of transport movements (see Figure 16). The six construction flow types are:

1. **Concrete**

The first construction flow type is concrete delivered with concrete mixers. The production and transport of concrete are dedicated to concrete specialists. One supplier was responsible for this material flow in this construction project. Concrete mixers always drive with their maximum load factor. These heavy-duty trucks are the only way to transport concrete. Hence, logistics solutions cannot be applied in this construction flow except to transport with a ZE concrete mixer. Technological developments in ZE trucks are necessary to be prepared for the ZE zones.

2. **Shell construction large**

The materials needed in this construction flow type are materials for foundation, floors, stairs and reinforcement of the floors and walls. Piles are drilled into the ground with a pile driver to transfer the building loads onto the load-bearing soil. The stairs and part of the floors are made prefab.

3. **Shell construction load carriers**

The materials in shell construction phase that fit on load carriers (e.g. pallets) are separated from the shell construction large. Materials used for this type are window frames, bricks, natural stones, anchors and timber frame constructions.

4. Bulk

These are the unpackaged raw materials delivered in a high amount. Concrete is an example of bulk. However, in these construction flow types concrete is separated because it is wet bulk. Other examples are bricks, sand, wood and steel.

5. Completion construction

The shell construction has been completed in this phase. Typical materials for completion construction are materials for electricity, sanitary, tiling, painting, plasterwork and pipes. The construction project has been completed at the end of this material flow. The completion construction is split up into large parts and small parts. The large parts are typically recessed products such as kitchens and sanitary. The small parts are the portable packages often packed in boxes.

6. Heavy equipment

The heavy equipment considered in this flow is the heavy equipment that stays for a longer period at the construction site. The heavy equipment used for the 5,000 m^2 project is support scaffolding, façade scaffolding, a construction crane and wall boxes. Other heavy equipment can also be cranes that is part of the transport service but is not part of this flow. Logistics service providers have cranes attached to their trucks to move their supply at the desired height. These are the loader crane trucks (see 4.1 Vehicles used in construction logistics).

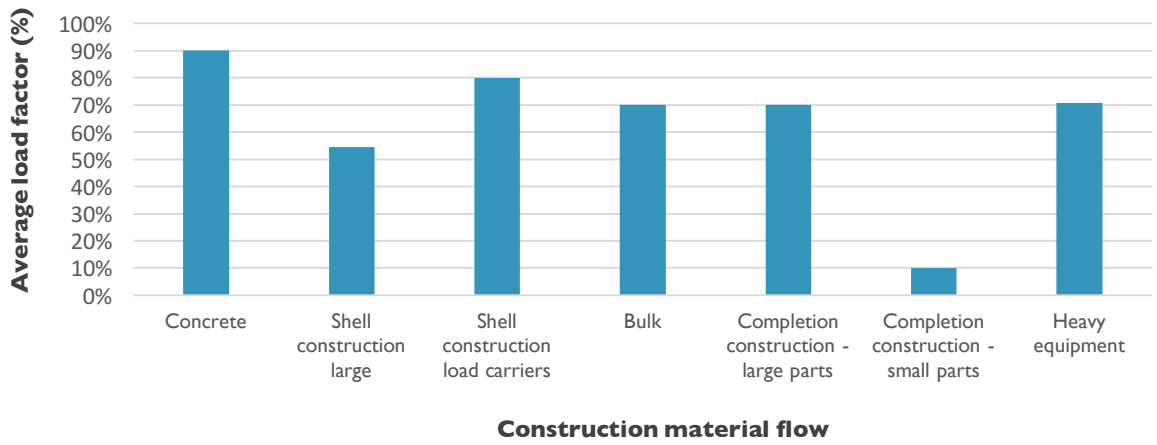


Figure 16: Average load factor new construction project for each construction material flow (source: anonymized dataset of a new 5000 m^2 GFA construction project in Amsterdam)

4.3 CONSTRUCTION LOGISTICS URBAN AREA

An estimate of logistics characteristics is used to evaluate the alternatives on the impact of the criteria. Construction projects are categorized on size, as discussed in 3.1 SMEs and their projects, and on type to search for solutions specific on type projects. Transformation and renovation mostly have the same characteristics because the building shell is already there. For this reason, these types of projects are taken together.

The type of projects' characteristics has also been used in a research on urban area logistics (Otten, Meerwaldt, & Den Boer, 2016). The total distance driven in urban areas by the construction sector

(left-hand side graph) is visualized in Figure 17. In the graph on the right-hand side, the distance driven for waste transport is shown where the construction waste flow is the most significant. This data is based on the entire construction sector and not focused on small-scale construction projects. The data is collected by using both a top-down method which starts with formulating generic principles and ends with the details and a bottom-up method that process information based on analysis of specific characteristics and micro attributes.

In this case, the transport requirement per unit is first looked at, which in this case is the transport requirement per construction site. Among the construction sites, a distinction is made between the construction sectors of residential construction, utility construction and infrastructure construction, and according to the type of construction, which are new construction, renovation and maintenance. Based on needs, a calculation has been made that has been scaled up for the entire Netherlands.

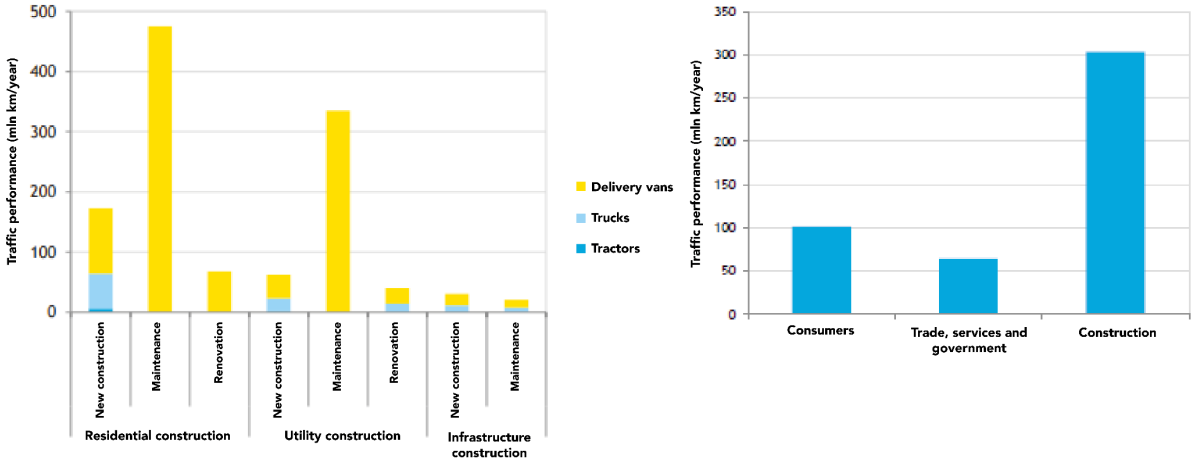


Figure 17: Total distance driven in urban areas in the construction sector (Otten, Meerwaldt, & Den Boer, 2016)

Several interesting conclusions can be drawn from Figure 17. Infrastructure construction is irrelevant for this thesis project because it is not construction that delivers buildings as an end product and is often specialized by large companies and not by SMEs. Maintenance, the most prominent and largest bar form the left diagram, contributes the most to the kilometers driven in urban areas, both in residential and non-residential construction. Of all the kilometers that are driven in maintenance, only delivery vans are used. Delivery vans have a low load capacity because of their maximum allowed weight and therefore pallets and roll containers are usually not transported with a delivery van. A large part of the transport in maintenance is parts and general cargo such as paint. The volume of materials required for maintenance is minimal and can be taken by the contractors themselves with the delivery vans.

Next in Figure 17 is the new construction in residential construction. This is the group where most trucks and tractor trailers (heavy-duty transport) are used. This is because new construction consists partly of shell construction that maintenance and renovation do not have. In the shell construction phase, you must deal with a significant amount of large heavy elements and that is why most heavy-duty transport is used here. There is no heavy-duty transport in residential renovation which depends on how the source defines renovation work. In the research of Otten, Meerwaldt and Den Boer (2016), there is an assumption that only delivery vans are used in maintenance and renovation in residential construction and maintenance of utility construction. However, from the interviews, it can be

concluded that the assumption is incorrect in the case that box trucks are not considered as a delivery van. Wholesalers make use of box trucks to supply to construction sites and not delivery vans because of the maximum load capacity of these vehicles which is too low for delivery vans. Therefore, material supply for renovation projects in residential construction is delivered with box trucks.

Nevertheless, the share of delivery vans in transport movements for renovation in residential construction is high. That leads to the last conclusion which is that the logistics solutions in Chapter 7: Feasible logistics solutions should focus on the delivery vans' usage. This is one of the most used means of transport and contributes the most to the problem situation in small-scale construction projects.

4.4 TRANSPORT MOVEMENTS

The reason why transport is needed is necessary to determine possible solutions. The transport movements from and towards a construction site can be split up into three parts. All transport movements occurring in small-scale construction projects are visualized in Figure 19. The three parts are:

- Material transport
- Personnel transport
- Equipment transport

The orange arrow between tools and subcontractors is an aspect to mention. The respondents in the interviews were asked about how personnel transport is organized in small-scale construction. The main problem addressed by the respondents was that the subcontractors, that are mostly freelancers, have their own delivery van and always use these delivery vans to drive to the construction site and to carry their tools. This is an important aspect of the problem situation because possible logistics solutions to shift subcontractors to ZE need to incorporate that their tools are available at the construction site. There are two reasons why the subcontractors do not leave their tools at the site: multiple jobs at different construction sites and theft. These reasons will be considered and addressed in the solutions proposal (7.2 Allocation of feasible logistics solutions).

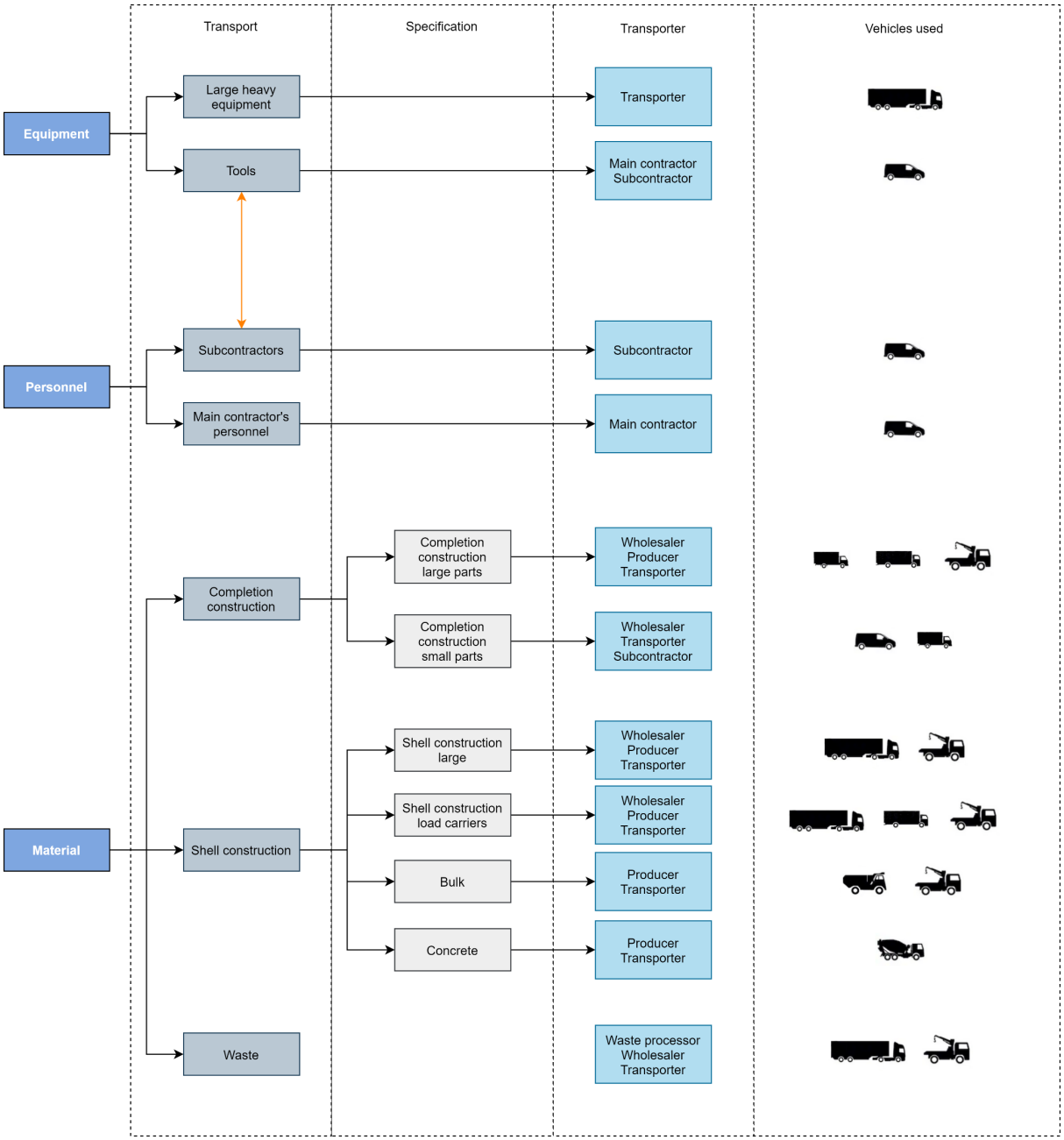


Figure 18: Transport overview construction logistics

4.4.1 MATERIAL TRANSPORT

The project's size of Figure 16's example case is large enough that the logistics work in a way that all materials are delivered instead of picked up. This is a general trend in new construction. One interviewed contractor only has the materials delivered to the construction site by suppliers and that contractor does not pick up the materials. The only case when they do pick up the materials is in case of an emergency. The construction projects constructed by this contractor are in the category small. The same holds for another interviewed contractor, all the materials are being delivered. This contractor picks up materials at least as possible and mentions that every trip to the wholesaler and back results in extra costs. Furthermore, the smaller a project becomes the more materials are being picked up. For large projects, it is worthwhile to arrange the procurement at the office. If the order is

large enough, then it is worth the effort for the project leader to do the procurement himself. If the order is small, then the procurement is being delegated and it is more likely to have someone drive back and forth to pick up the materials. The likelihood of when materials are delivered is represented in Table 8. The scale used for this table is: very low / low / moderate / high / very high.

Table 8: The likelihood that materials are being delivered instead of picked up to the construction site

Project size	Main contractor	Subcontractor
Micro	Moderate	Very low
Small	High	Low
Medium	Very high	Moderate

An anonymized dataset of eight customers has been provided by a wholesaler. This wholesaler has its focus on small-scale construction projects and therefore their customer base fits perfectly in this thesis project. The eight customers' data all consists of construction projects in urban areas and are recurring customers of the wholesaler. All customers fit in the category micro except for customer 8 who fits in the category small. Contractors have the tendency to be loyal to their wholesalers and it is unusual that they buy their materials at different wholesalers. Dependent on the location of the construction site and the nearest establishment of the wholesaler the travel time has been determined with Google Maps. The travel time and information about the pickup or delivery orders can be found in Appendix VI. This travel time is based on the time needed to drive from the wholesaler's establishment to the construction site. Material handling is not included in this travel time.

Most of the projects are either only delivered by the wholesaler or picked up by the customer. Some projects have both pickup and delivery. All the data about pickup, delivery and travel time to the nearest wholesaler is summarized in the box and whisker plot (Figure 19). The middle line of the blue box is the median or the middle number. The cross in the box is the mean. The median splits up the data set into a bottom and top half. The top line of the box is the median of the dataset's top half and the bottom line of the box is the median of the dataset's bottom half. The whiskers, that is the vertical line with a top and bottom horizontal line, are the beginning and end thus the dataset's minimum and maximum value. The interquartile range (IQR) is the distance between the first and third quartile thus the range of the blue box. If a data point exceeds a distance of 1.5 times the IQR below the first quartile or above the third quartile it is considered an outlier. The outliers are shown as the blue dots above the top whiskers for all three box and whisker plots.

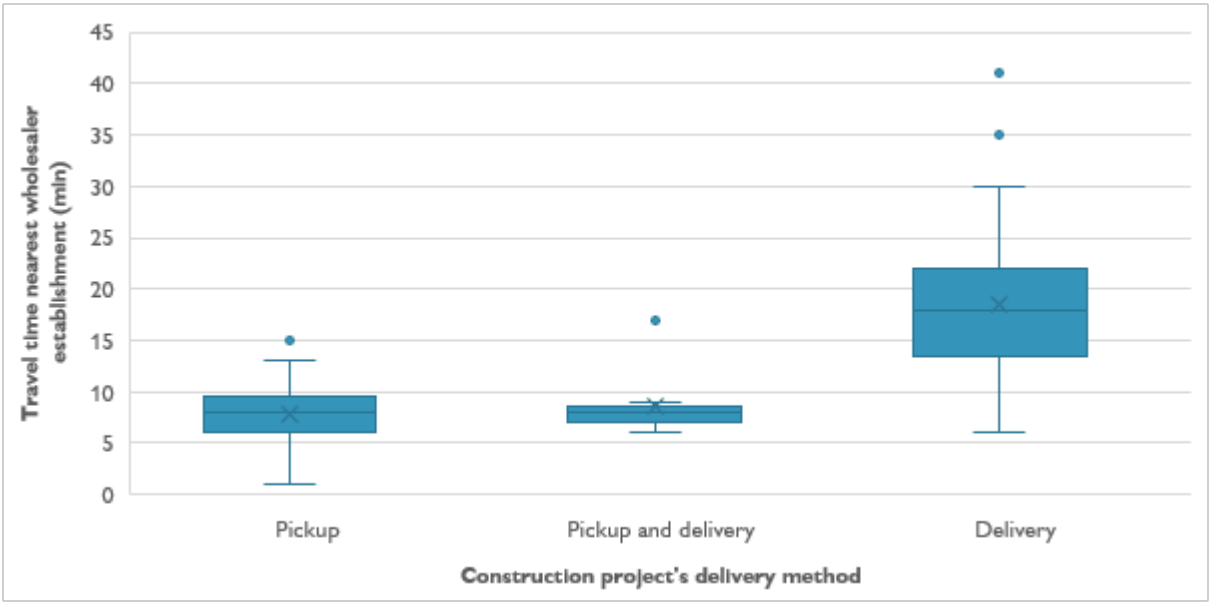


Figure 19: Box and whisker plot of pickup or delivery of materials from a wholesaler based on unidirectional travel time on road+

The conclusion that can be drawn from Figure 19 is that the contractors choose for delivery of materials the further away the construction site is from the nearest wholesaler. There are only deliveries if the travel time is more than 15 minutes. The travel time is unidirectional. Consequently, when the travel time is 15 minutes it will take them 30 minutes driving to pick up the materials. Furthermore, the time to purchase and load in the materials and to park the vehicle is not even included and therefore it can take quickly about an hour to pick up the materials. The box and whisker plot shows that the contractors are aware and prefer delivery if it takes too much time.

The pickup and delivery box plot in the middle are the residences where pickup and delivery both occur. The travel time of these residences is similar to the pickup residences. However, below six minutes there are no deliveries. A reason could be that they prefer to drop by and hang out at the establishment. Two wholesalers' respondents mentioned that their customers, the freelancers, prefer to pick up their materials because of the social aspect. The construction sector is traditional and one of the wholesaler's respondents is only in the webshop for two or three years which confirms that they are behind compared to other sectors.

In the interviews, the respondents said that contractors that are good at their job have decent planning. However, most of them are not capable of planning. Contractors have three options to order at the wholesaler: via the webshop, by telephone or directly at the counter. They have the option to suggest when they need their products. The wholesaler's respondent stated that approximately 70% of the orders are "today for tomorrow" meaning that they order for the next day. This majority of customers realize during the day what they need for their tasks and order to either pick it up or let it deliver the next day. Even though most customers are incapable of planning for more than a day, they can choose to deliver their materials. This implies that pick up is not always necessary. The time that materials are delivered is mostly in the morning. Contractors are traditional and want their materials delivered as early as possible. A wholesaler has five supply time slots: at 7.00, before 9.00, before 12.00 after 12.00 and after 16.00. After 16.00 rarely occurs. The reason why they want their delivery early is for the certainty that the materials will be delivered.

There are some limitations to the box and whisker plot. Firstly, is that the dataset only consists out of eight customers. The total ratio of pickups/deliveries based on all orders is 31%. The wholesalers' respondents speak of an average 50% ratio and therefore the 31% ratio contradicts that estimate. Secondly, is because of the low number of customer data the personal backgrounds of the customers have a large impact on the results. The dataset consists out of 223 deliveries and 98 pickups. It could be that most of the eight customers are decent in planning causing the high number of deliveries. Thirdly, is that it could be that the pickup order is a rush order. Without the materials, customers cannot perform their daily tasks and therefore the materials are purchased directly during the day. The dataset only provides that date of an order and not the time. For that reason, it is unknown whether it is a regular order at the beginning of the day or a rush order.

The renovation project in Amsterdam (size medium) contains detailed information about the distance traveled by suppliers. A part of all materials was delivered to a construction consolidation center (CCC) and afterward transported over water to the construction site. All transport movements towards the CCC and to the construction site are visualized in Figure 20 and grouped on color if the delivery is to the CCC or direct from the supplier towards the construction site. There are two outliers in this graph. The supplier of these two outlier transport movements is a supplier of floor elements situated in Switzerland and had to drive 852 km to reach the CCC. The rest of the supply is domestic and less than 200 km away. The first 81 transport movements shown in the scatter plot are the deliveries from the supplier to the CCC. The other 328 transport movements are direct deliveries from the suppliers towards the construction site. A large share of the direct deliveries to the site are small trips and are less than 10 km. Almost all of these short trips are delivered with delivery vans and the materials delivered were transported in boxes.

The large advantage of the CCC as an intermediary station is that vehicles can maximize their load factor because there is no limitation of storage capacity at the CCC. There is no data available about the load factor but an analysis of the type and quantity of the materials transported shows that these direct transport movements of suppliers to the construction site have a low load factor. A CCC is an example of a hub that functions as a central transshipment point where different suppliers can be combined. A detailed explanation of the operations of a CCC and hubs is explained in Appendix VII.

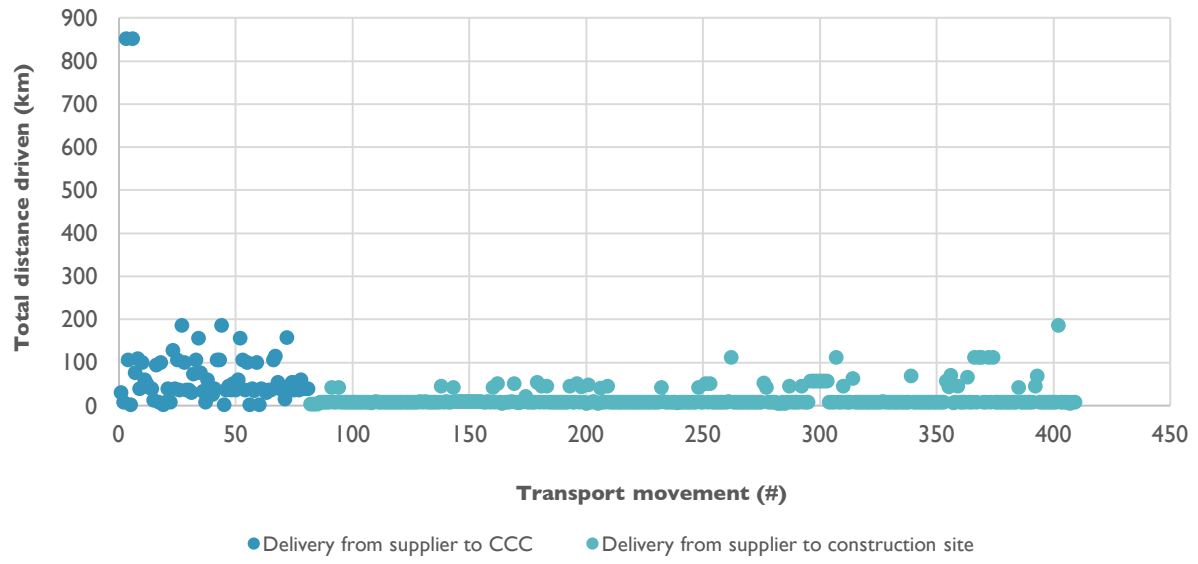


Figure 20: Total distance driven for each transport movement from suppliers to CCC and the construction site (Own figure based on an anonymized dataset of an 82 rooms hotel renovation project in Amsterdam)

Waste transport fits also in the category of material transport. An interviewed contractor works with containers for waste. The use of the waste container is a traditional and most often used way of depositing waste. There are different sizes of containers used for waste. Beelen, a large waste processing company, has three sizes for containers. These are 3, 6 and 9 cubic meters. The waste processing company delivers the container at the desired location near the construction site and picks it up when it is full. The reason why most contractors use this option is that they have one large container to dump all the waste. A project delivers a large variety of waste. The waste processing company returns the container filled with waste back to their establishment and separates the waste.

Another way of waste storage is the use of Bouwbewust boxes or bigbags. BouwBewust boxes are used to deliver materials that can afterward be used as a waste container. It is possible to put a pallet inside the BouwBewust box. This is an invention of wholesaler BMN together with waste processor Suez and the boxes are small two cubic meters containers that can be hoisted to the desired height. These boxes fit the characteristics of small-scale urban area construction projects well because these boxes are small. Bigbags are, as their name implies, large bags made of woven plastic. Forklift trucks can lift and move the bigbags because of the carrying loops on top. These waste transport solutions show that it is beneficial to take the waste return directly from the construction site when delivering materials.

4.4.2 PERSONNEL TRANSPORT

Personnel transport is all personnel working at the construction site. These are the main contractor's personnel and the hired subcontractors. The main contractor's personnel make use of the vehicle fleet owned by the main contractor. An interviewed contractor has switched to an entirely electric vehicle fleet. This contractor started with this sustainable ambition in a time where this was exceptional. Nowadays, other main contractors are also switching over to sustainable energy usage. Their personnel use this vehicle fleet and therefore can arrive in urban areas with ZE. The use of public transport to transport personnel is doable but difficult. The personnel starts at 7.00 hours in the morning. The use of a delivery van takes in general significantly less time than public transport. However, this is location dependent.

Subcontractors' transport is not managed by the main contractor as it is their own responsibility on how to arrive at the destination. All subcontractors have their own vehicles. The smaller a stakeholder becomes the more difficult it is to switch to a sustainable vehicle. A freelancer does not have the financial resources to purchase an electric delivery van. Because they do not have the financial resources and their transport is their own responsibility this is a major problem to deal with.

SME main contractors are currently in a situation where a choice must be made in whether to switch to electric or remain purchasing fossil fuel vehicles. Two interviewed contractors have problems with this dilemma. There are two reasons for this dilemma which are the financial resources and the charging infrastructure. Electric delivery vans are relatively much more expensive (see 4.1.1 Delivery vans).

4.4.3 EQUIPMENT TRANSPORT

There are two types of equipment used in construction: heavy equipment and tools. An overview of the equipment is visualized in Figure 21 based on products offered on the internet by heavy equipment companies. A variety of objects fills in the category of heavy equipment. The directly related heavy equipment for construction is the machines. These are for example pile drivers. The large machines are only used in shell construction and therefore in new construction and not in renovation. The heavy machines are transported to the location on a trailer by a tractor which is heavy transport. Temporary housing are facilities needed for personnel such as eating spaces, mobile toilets and containers. Eating spaces are large and mostly transported with a tractor. Such a tractor has an attached loader crane to directly unload the eating space at the desired location. The construction site design consists out of for example aggregates, water supply units or road plates. Vertical transport can be elevators, aerial work platforms or telehandlers. The difference between aerial work platforms and telehandlers is that a telehandler is used on rough terrain, and thus only in shell construction, to transport materials. A telehandler has a driver operating the machine whereas an aerial work platform is operated by using a control board within the cage. These are used to work on the desired height. An aerial work platform is therefore more common in renovation projects. However, scaffolding is the usual way of working on façades. The tools are the small equipment necessary for the manual work of the contractors. These are specified on the contractor's discipline, whether the contractor is a carpenter, painter, plasterer or plumber. For example, carpenters' standard equipment consists of a set of handsaws and electric saws, screwdrivers in all kinds of variants, accessories such as sandpaper or wood glue, abrasive tools and measuring tools.

Heavy equipment is transported on either a tractor or a loader crane truck depending on the size and weight of the heavy equipment. A large machine such as a pile driver is transported by a tractor whereas a mobile toilet is transported by a loader crane truck. Tools are transported in delivery vans. The contractors bring their tools. Subcontractors always take their tools return. A common problem on construction sites is the theft of each other's tools. Contractors do not trust each other due to the variety of enterprises working at the site. Main contractors' personnel do not have the same problem as the subcontractors because the tools are owned by the main contractor and not by themselves.

The use of heavy equipment in renovation projects is limited. Machines and construction site designs are only used in new construction projects. Temporary housing is almost never present in micro renovation projects because these projects are too small. Scaffolding and a mobile toilet is the only heavy equipment that is present in both renovation and new construction projects. The use of vertical transport in renovation projects depends on the construction project and how much materials need to be transported vertically. However, most of the time materials are delivered with a loader crane truck and therefore vertical transport equipment is unnecessary. Only in medium renovation projects, it is more common to have vertical transport equipment because the quantity of material supply is too high to make use of a loader crane truck.

These insights show that heavy equipment is mostly present in new construction and not in renovation. The transport of heavy equipment is only a small share of the total transport movements in a renovation construction project. Furthermore, logistics solutions for heavy equipment are limited in possibilities. Hence, logistics solutions for heavy equipment are less important. However, the transport of tools is of high importance because transport is combined with personnel transport.

Heavy equipment	Machines	New construction
	Temporary housing	New construction Small/medium renovation
	Construction site design/energy sources	New construction
	Vertical transport	New construction Medium renovation
	Scaffolding	New construction Renovation
Tools	Small equipment	New construction Renovation

Figure 21: Overview of construction projects' heavy equipment use with its coherent presence

4.5 CONCLUSIONS ON CURRENT LOGISTICS STRUCTURES

What are the current logistics structures for small-scale construction projects?

The current logistics structures have been formulated on vehicles used and on the transport movements' cause. The vehicles used in small-scale renovation construction projects are mostly delivery vans, box trucks and loader crane trucks and sometimes heavy trucks and tractors. Dump trucks and concrete mixers are only used for new construction. These vehicles are either used to transport personnel, materials, tools or heavy equipment. Consequently, more in-depth analysis has been conducted on delivery vans and trucks because these are the primarily used vehicles in small-scale renovation construction projects.

Delivery vans depreciation age leads to an interesting and disturbing conclusion. An SME contractor's delivery van depreciates on average in 7 years and a freelancer contractor's delivery van on average 9.5 years. This implies that at this moment already a part of the delivery van fleet will not depreciate before the ZE zones will be set in 2025. Then the contractors will still have a delivery van that is too new to be replaced with a ZE delivery van. Especially for freelancers, this is disturbing because the awareness about the ZE zones is less present among the freelancers than among the SME contractors. Hence, the urgency of the problem must be communicated to the contractors.

Trucks have a transitional agreement for the ZE zones towards 2030 and therefore the urgency is less present. However, electric trucks are still extremely rare and expensive and will start to be competitive from 2028. A prediction is that in 2028 in total 2% of the trucks will be electric. Those trucks need to be distributed not only over the construction sector but also over other sectors so it is unlikely that electric trucks can replace all construction trucks.

Analysis of the emissions of vehicles shows that vehicles can never be ZE for 100%. Particulate matter (PM) will always be emitted when using vehicles because of brake wear, tire wear and abrasion of road surface but the emission is low. The different EU emission standards have been set to oblige vehicle manufacturers to produce sustainable vehicles. Consequently, Euro VI trucks and Euro 6 passenger cars and delivery vans are significantly more sustainable than previous emission standards. The ZE

zones regulations have a transitional arrangement for Euro VI trucks and the standards show that it is a fair arrangement because of the sustainability of Euro VI trucks.

The logistics structures of construction projects can be grouped into six construction flow types: concrete, shell construction large, shell construction load carriers, bulk, completion construction and heavy equipment. From these six construction flow types, mostly completion construction is present in small-scale renovation construction projects and occasionally bulk and heavy equipment. Completion construction can be separated into large parts and small parts. Data on a medium new construction project shows that the average load factor of the transport of small parts within completion construction has by far the lowest load factor compared to other construction flow types. This shows that small-scale renovation projects still can have a lot of improvement to increase the load factor and to decrease the number of transport movements with the use of logistics solutions.

The logistics structures are composed out of three parts: material, personnel and equipment (heavy equipment and tools). The vehicles used within these parts are different. Delivery vans are used for personnel and tools transport. Within small-scale construction projects, half of the materials are picked up by the contractors thus the delivery vans also contribute to material transport. Data shows that contractors can plan their procurement and let the materials be delivered if necessary. That insight is crucial to the requirements of feasible logistics solutions in Chapter 7: Feasible logistics solutions. Heavy equipment is rarely used within small-scale renovation projects and therefore less important for logistics solutions. The materials that are delivered by the supplier or transporter are delivered with either box trucks or loader crane trucks and sometimes tractors. Loader crane trucks are less urgent to apply logistics solutions on because the load factor is already high for these trucks and possible logistics solutions are limited.

This chapter has been extremely important within the analysis step of the basic design cycle to design the product. Now that it is known how the logistics structures are set up, feasible logistics solutions can be determined which will be performed in Chapter 7: Feasible logistics solutions. First, a stakeholder analysis will be applied in Chapter 5: Stakeholders' objectives and roles to better understand the stakeholders' roles within the supply chain to finalize the analysis step in the basic design cycle.

Feasible logistics solutions design requirements that were found in this chapter are:

- Logistics solution(s) must give alternatives for the use of delivery vans. (Functional requirement)
- Logistics solution(s) must be applicable for personnel, materials, tools and heavy equipment transport movements and indicate the solutions separately. (Functional requirement)
- Logistics solution(s) for materials must make use of hubs. (Functional requirement)
- Logistics solution(s) must allow contractors to have the materials delivered rather than picked up. (Functional requirement)
- Logistics solution(s) for heavy equipment in renovation projects are of less importance. (Non-functional requirement)
- Logistics solution(s) for tools are of high importance. (Non-functional requirement)
- Logistics solution(s) must deal with the presence of necessary tools at the construction site. (Functional requirement)
- Logistics solution(s) must focus initially on electric trucks as ZE alternative. (Non-functional requirement)
- Logistics solution(s) must focus on completion construction transport movements. (Non-functional requirement)

- Logistics solution(s) for waste must focus on combining the delivery of materials with returning waste. (Non-functional requirement)
- Logistics solution(s) must explain the difficult transport flows where exemptions should be made if ZE logistics is infeasible. (Non-functional requirement)
- Logistic(s) solutions must deal with the limited space available at a construction site. (Non-functional requirement)
- Micro logistics solutions will not make use of a CCC. (Non-functional requirement)

The booklet design requirements that were found in this chapter are:

- The booklet must address the urgency of the problem. (Non-functional requirement)
- The booklet must categorize logistics solutions on personnel, material, tools and heavy equipment. (Non-functional requirement)

CHAPTER 5: STAKEHOLDERS' OBJECTIVES AND ROLES

SQ3: How do the objectives and roles of the various stakeholders involved affect the transport movements in construction logistics?

This chapter will make a stakeholder analysis that will result in information about the objectives and roles of the various stakeholders within small-scale construction projects' logistics. Three matrices will be constructed to analyze the stakeholders and their relations with each other and with the problem formulation. Firstly, the analysis will be performed. That analysis ends up with a new vision on the problem formulation that will be confronted with that vision. The analysis also ends with a power-interest matrix that leads to new insights and conclusions. Secondly, an influence-impact matrix is constructed that results in additional insights next to the power-interest matrix. Thirdly, a stakeholder engagement matrix is constructed. Lastly, conclusions on the stakeholder analysis and matrices will be made. This is the third and final step in the analysis step of the basic design cycle.

5.1 STAKEHOLDER ANALYSIS

The interviews of the stakeholders aim to discover the perspectives of all stakeholders, to analyze how the construction logistics structures are set up and what their perspectives are about possible logistics solutions. The list of interviewed stakeholders and interview protocol can be found in Table 1 and Appendix III. Enserink et al. (2010) came up with a six-step stakeholder analysis based on various documents in the stakeholder analysis field. These six steps are used in this thesis project. Normally, stakeholder analysis methods focus on dimensions of power and interests of actors. The actor analysis in Enserink et al. (2010) also covers network structure and the perception of actors. The difference between actors and stakeholders is that actors play an active role while stakeholders a passive role. The actions of an actor will make an impact on stakeholders. All the steps taken for this analysis are represented in Appendix VIII. The first four steps are less interesting and steps five and six are the eventual results of the analysis that are given in this paragraph. Step five ends with the power interest-matrix and step six is the confrontation of the initial problem formulation that will be given in this paragraph. A general note is that the stakeholder suppliers are referred to in the analysis and the rest of this thesis project. The suppliers are the wholesalers and producers. Wholesalers do not produce but are only traders in products. However, wholesalers and producers are both the suppliers of materials.

5.1.1 POWER-INTEREST MATRIX

There are several conclusions that can be drawn from the power-interest matrix shown in Figure 22. The first conclusion for who the actions apply (monitor, keep satisfied, keep informed, manage closely) and what those actions are. These actions are described in Table 9.

Table 9: Necessary actions stakeholders must take based on power-interest matrix

Stakeholder (subject)	Stakeholder (object)	Type of action	Action
Main contractors Suppliers Transporters	Main contractors Suppliers Transporters	Manage closely	The long-term relationships that these stakeholders have with each other must be maintained. If a stakeholder has a

	Subcontractors		new idea about how to set up a logistics solutions, the other stakeholders must listen and think along with that stakeholder.
Main contractors	Subcontractors	Keep satisfied	The main contractors must keep their subcontractors satisfied to not lose them to competitors.
Main contractors Subcontractors Suppliers Transporters	Municipalities	Keep satisfied	The municipalities have set regulations that the stakeholders (subject) must adhere to. These regulations, the upcoming ZE zones, are the foundation of this thesis project. This will result in that stakeholders are going to change themselves in how they operate because they are a highly traditional sector.
Municipalities Main contractors	Local residents	Monitor	Local residents should not experience any nuisance and must be monitored if this is the case.
Main contractors	Clients	Monitor	The main contractor must monitor the clients because they are paying the main contractor.

The actions that apply to subcontractors are the most interesting that will lead to the second conclusion. Subcontractors are on the edge of key player and context setter even though they are the problem owner together with the main contractors. Therefore, there are two actions that apply to them: keep satisfied and manage closely. An interviewed main contractor mentioned the problem that they can oblige them to adopt logistics solutions. This corresponds with the action to manage closely. However, the main contractor is afraid of losing their subcontractor to a competitor if there are too many rules that the subcontractor must adhere to. That is why the position on the edge with context setter is interesting. The main contractors want to keep their subcontractors satisfied.

The third conclusion is the position of municipalities which is that they are a context setter and not a key player. Reducing emissions and increasing livability and accessibility are the municipalities' goal and not of anybody else. Their interest is limited because the ZE zone regulation has already been made and their intention is that the key players will find solutions themselves. The key players are still not acting enough to do something with the problem situation and are waiting for others to make a move. Municipalities' interest should increase to initiate the key players to move. Their opinion is that the market forces will provide the necessary solutions. However, Figure 13 already shows that fossil fuel delivery vans are still ordered as usual. The subcontractors even have their delivery vans for a longer period than main contractors because their organization is smaller as shown in Figure 14. This implies that already a large share of the subcontractors has a delivery van that is not depreciated in 2025. Thereafter, they are banned to enter urban areas with their delivery van. The longer everybody waits, the larger that share of contractors will become.

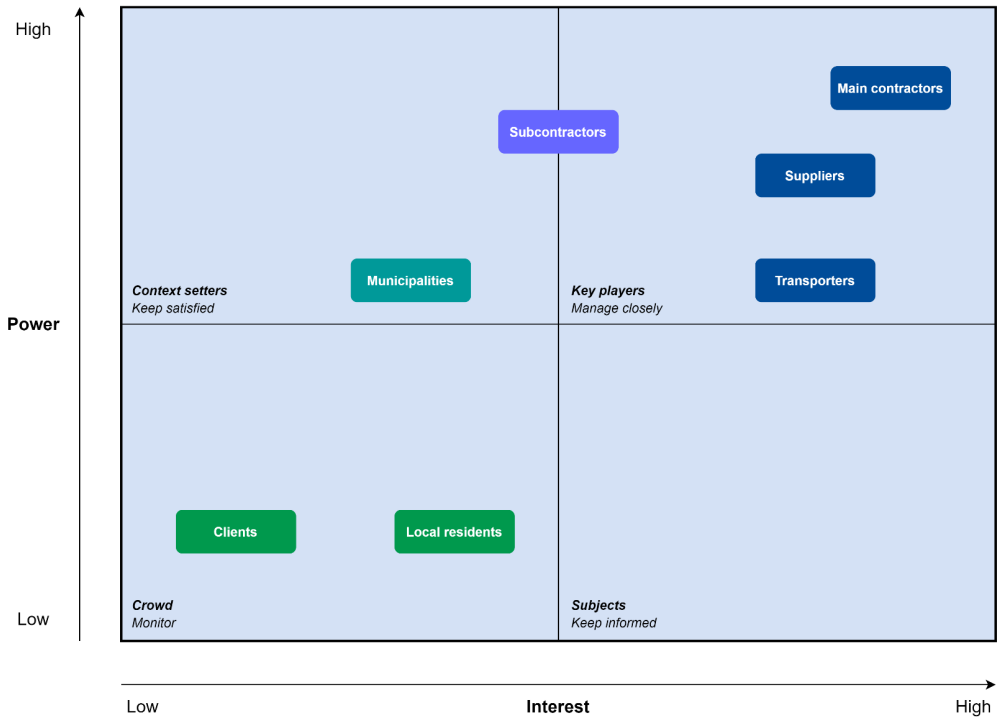


Figure 22: Power-interest matrix

5.1.2 INITIAL PROBLEM FORMULATION CONRONTED WITH FINDINGS

Generally, subcontractors do not care about sustainability and therefore are not willing to pay for sustainable alternatives if the logistics costs increase. Only when the legislations are introduced that it will be forbidden to drive with fossil fuel vehicles from 2025 and fossil fuel trucks from 2030 they are confronted with the problem situation. At this moment, their interest in the problem situation is too low. Contractors (subcontractors and main contractors) are both the problem owner. They need to have sustainable alternatives in 2025 to transport with ZE in urban areas. Subcontractors only care about executing their job and main contractors want that their subcontractors deliver the quality that they desire within the time they have. The subcontractors purchase their own materials and decide how they arrive at the construction site. Even though the main contractors' cognitive resources are high, they are afraid to oblige their subcontractors to switch to sustainable logistics solutions.

The subcontractors' interest is medium and not high as shown in Figure 22. They are on the edge of being a context setter or key player. It is important to incentivize the subcontractors in such a way that they are willing to adapt themselves. Main contractors are more organized and already think about possible logistics solutions to confront the prospective problem situation. The other key players, the suppliers and transporters, are willing to help because it is one of their main objectives to deliver high service to the contractors.

This stakeholder analysis shows that the problem does not need to be addressed only on a technical level (how to apply logistics solutions) but also on a human level (the role of people in transport). The people who are responsible for the transport movements still need to be encouraged to apply a logistics solution if a logistics solution can decrease transport movements significantly without too many additional costs.

5.2 INFLUENCE-IMPACT MATRIX

Similarly, how the power-interest matrix is plotted, an influence-impact matrix can be plotted. The influence a stakeholder has is how actively they are involved or the extent to which a stakeholder can persuade others in decision making (Bevis, 2015). The impact is the ability to bring change. The matrix is shown in Figure 23. The positions where the stakeholders are placed are close to the location in the power-interest matrix (Figure 22). However, the small differences matter in which they can make an impact and help with finding solutions.

The same as for the power-interest matrix, several conclusions can be drawn from the influence-impact matrix (Figure 23). The first conclusion is for who the actions apply and what those actions are. These findings are shown in Table 10 below.

Table 10: Necessary actions stakeholders must take based on influence-impact matrix

Stakeholder (subject)	Stakeholder (object)	Type of action	Action
Main contractors Suppliers Transporters	Main contractors Suppliers Transporters	Manage closely	Manage each other closely to see if their position is changing. If a stakeholder's impact or influence changes, opportunities arise to set up new logistics solutions.
Main contractors Suppliers Transporters	Municipalities	Keep informed	If the subject stakeholders know more about logistics solutions, they must keep the municipalities informed. An interviewed municipality mention that he is curious about such new knowledge.
Main contractors Suppliers Transporters	Subcontractors	Keep informed	If the subject stakeholders know more about logistics solutions, they must keep the subcontractors informed.
Municipalities Main contractors	Local residents	Monitor	Local residents should not experience any nuisance and must be monitored if this is the case.
Main contractors	Clients	Keep informed	The main contractors are hired by the clients so the main contractors must keep the clients informed about any changes in innovation regarding logistics solutions.
Main contractors	Clients	Monitor	The clients must remain on the main contractor's radar. Possibly, clients' interest change about how their projects must be executed and that can allow for applying new logistics solutions.

The second conclusion is that municipalities are close to the 'manage closely' quadrant. In case that the main contractors, suppliers or transporters have logistics solutions that require stimulation from municipalities they can move more upwards in the matrix meaning that they become more actively involved. An example of such a logistics solution is the use of a minicontainer (which will be explained later in 7.2.2 Small renovation projects). The municipality can help to make it more feasible. Municipalities can make restrictions for suppliers to deliver in neighborhoods if minicontainers are present. Restrictions that oblige the suppliers to make use of the minicontainer when the materials are suited to be delivered in a minicontainer. This is an example of municipalities getting more actively involved.

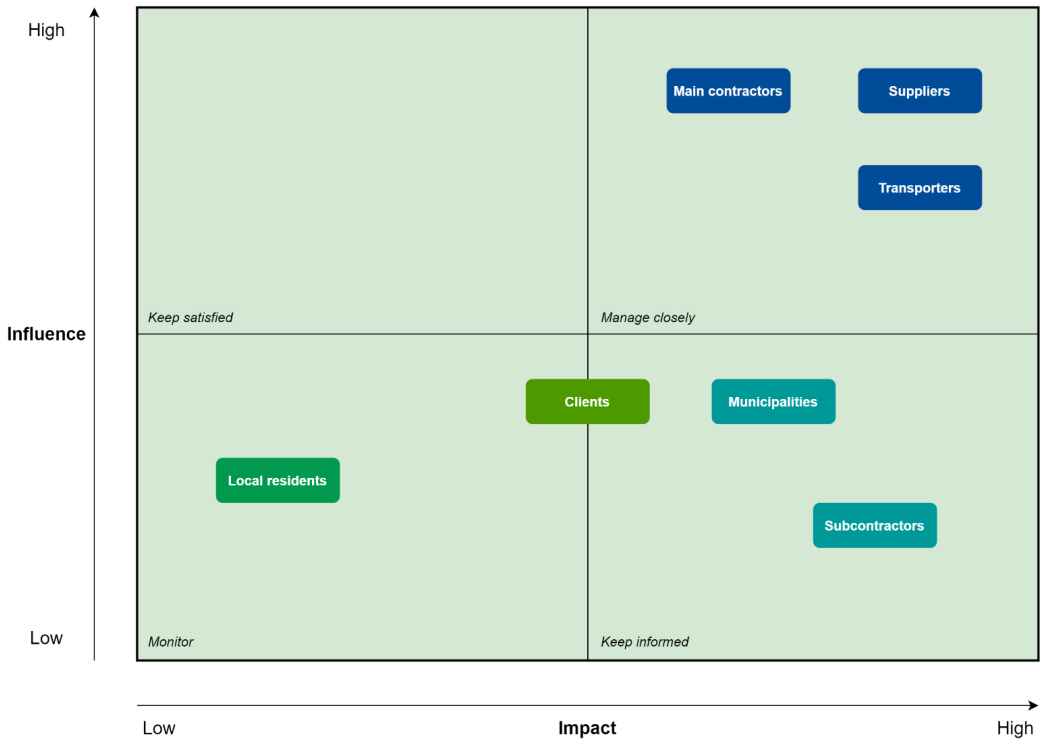


Figure 23: Influence-impact matrix

5.3 INSIGHTS OF POWER-INTEREST MATRIX AND INFLUENCE-IMPACT MATRIX

The applied stakeholder analysis in this chapter results in the power-interest and influence-impact matrices (see Figure 22 and Figure 23). The local residents are stakeholders affected by construction logistics but have limited power, interest, influence and impact. Clients have more impact as indicated by the interviewed contractors. However, their impact is that contractors are hindered by clients for two reasons. The clients will not pay more to fund logistics solutions for improving sustainability and clients want to minimize the time needed for construction, especially in renovation. These two reasons can cancel each other out. Contractors can reduce the construction time if materials are delivered just-in-time. Local residents are put out of their residences by the clients in renovation projects. The residents will receive compensation from the house owner, which is the client of the contractor. If the compensation costs are higher than the additional logistics costs, clients will be persuaded to pay for those logistics costs.

The municipalities stakeholder is placed in two quadrants in the two matrices. They are the context setters in the power-interest matrix and therefore need to be kept satisfied. In the influence-impact matrix, they need to be kept informed. The reason why the municipalities are in these different quadrants is that the interest and influence are low because they tend to be passive and prefer that the market will act upon the regulations of the ZE zones. The SME and freelancer contractors are difficult to reach and have an impact on. The municipality Rotterdam wants to help the smaller contractors but classifies them as the blind spot. Planned subsidies are focused on SMEs. This insight shows that municipalities are willing to help only if they know where to help. Therefore, the target audience of the eventual product of this thesis project must not only be contractors but also other stakeholders that have an impact on logistics solutions.

The key players (suppliers, main contractors and transporters) are in both matrices in the bottom right quadrant and must be managed closely. There are some small fluctuations in their positions between the two matrices. The main contractor is the most important stakeholder in the power-interest matrix whereas the supplier is the most important stakeholder in the influence-impact matrix. The main contractor is the one responsible for the entire construction project and is the client of the suppliers. The suppliers' business model is based on increasing sales and delivering a high-level service. The suppliers' and transporters' resources are of high importance for small-scale construction logistics because contractors do not have the vehicles to transport larger and/or heavier materials.

The problem owner addressed initially is the main contractor. This is only valid until 2025 because the main contractors need to have switched to ZE alternatives for urban area logistics from 2025. Afterward, the wholesalers and transporters will become the problem owner because trucks will be the major focus of attention between 2025 and 2030. Producers are not considered as problem owners because their business model is more on producing the material and less on service activities such as logistics. Generally, the transport will be outsourced to transporters (logistics service providers). The materials sold by the suppliers need to be delivered in the urban area. Logistics solutions are necessary to help them achieve the regulations. The municipalities are willing to adjust the regulations but only if the situation is close to 2030 and ZE trucks are unable to be used for the entire construction logistics. The regulations need to be achievable and realistic.

There are no conflicts between stakeholders concerning the problem situation. Everybody wants to decrease the transport movements and emissions of construction logistics. However, the requirements may not deliver additional costs to the relevant stakeholders. In that case, they are not willing to move. The benefits that a change in behavior deliver must exceed the costs. That is what makes subcontractors resistant. They are not against making construction logistics more sustainable but they are not willing to change themselves.

5.4 STAKEHOLDER ENGAGEMENT MATRIX

The stakeholder engagement matrix is to identify the current status of each stakeholder and the desired status (Alqaisi, 2018). This matrix is represented as a table because the position in the matrix does not matter, it is only relevant in which box within the table the stakeholder is represented. There are two letters that a stakeholder has in the matrix: letter C and letter D. These letters stand for the current status (C) and desired status (D). The stakeholder engagement matrix regarding small-scale construction logistics projects is shown below in Table 11.

Table 11: Stakeholder engagement matrix

Stakeholder	Unaware	Resistant	Neutral	Supportive	Leading
Municipalities			C	D	
Main contractors				C	D
Subcontractors		C	D		
Suppliers				CD	
Transporters				CD	
Clients	C			D	
Local residents			CD		

As described in previous paragraphs (5.1 Stakeholder analysis and 5.2 Influence-impact matrix) municipalities are holding back and therefore neutral. They are willing to be supportive but the market forces should allow them to. Furthermore, logistics is high on the agenda and there is a plan to

subsidize a maximum of 40% of the additional costs of an electric vehicle mentioned by the municipality respondent and by Van Gurp (2019). The interviewed main contractors mention that they are supportive but not leading. Some of them also indicate that they could be leading as a chain director. For that reason, their desired status is leading because of their impact on small-scale construction logistics is large. Subcontractors are resistant because they are conservative and are not willing to change. That does not imply that they are in conflict with other stakeholders. They are resistant to change their normal way of executing their project. Transporters and suppliers are more into making construction logistics more sustainable than contractors because their business model is based on it and is therefore already supportive. Especially transporters, who must distinguish themselves from competitors and are busy with ZE-logistics to be in front of their competitors. Clients are unaware of construction logistics because they only care about the construction work. However, large clients such as housing corporations and insurance companies must be supportive because it can also help them. These clients have many houses to be renovated and standardizing those renovations can reduce the costs and improve the construction logistics. For example, if the materials used to improve the isolation of houses are all the same, suppliers and transporters can think about distribution alternatives to transport those materials in a more innovative way. The local residents are neutral and could be resistant if the nuisance increase. Therefore, monitoring them and checking if they remain neutral is the only action that should be taken.

5.5 CONCLUSIONS ON OBJECTIVES AND ROLES OF STAKEHOLDERS

How do the objectives and roles of the various stakeholders involved affect the transport movements in construction logistics?

A discussion in construction logistics is who is going to be the chain director. The stakeholder engagement matrix shows that there is no stakeholder leading and the desired situation shows that the main contractors might be leading. That does not imply that they are the chain director. It is the combination with the other supportive stakeholders that will allow them to take a leading role. However, suppliers and transporters have a large impact on construction logistics because they deliver their materials to the construction site. The interaction between the stakeholders will allow them to reach the logistics solutions together instead of a chain director that organizes everything himself.

The power-interest matrix and influence-impact matrix show that municipalities are passive. This means that they rely on the market forces that will lead to logistics solutions. The objectives of the various stakeholders are still conservative and traditional and should change to switch to sustainable alternatives within construction logistics. The various stakeholders' roles and resources can help each other to achieve this. For example, transporters for completion construction do have the resources to switch to ZE last mile deliveries and those resources will only increase in the coming years. Furthermore, a supply chain can only be improved if stakeholders are collaborating with each other. The possible collaborations between the stakeholders to achieve those innovative logistics solutions need to be represented in the product to combine the stakeholders' resources since there are no conflicts between stakeholders concerning the problem situation.

This was the last chapter of the analysis step in the basic design cycle. The next two chapters (Chapter 7: Feasible logistics solutions and Chapter 8: Product: Instruction guide) will use the analysis made in this chapter and the previous two chapters, to come to a list of feasible logistics solutions and to develop the product to communicate this analysis to the relevant stakeholders.

Feasible logistics solutions design requirements that were found in this chapter are:

- Logistic(s) solutions must propose distribution solutions to allow the standardizing of materials. (Functional requirement)
- Logistic(s) solutions must help the subcontractors to be more supportive. (Functional requirement)

The booklet design requirements that were found in this chapter are:

- The booklet's target audience is the key players and the context setters: contractors, transporters, suppliers and municipalities. (Non-functional requirement)
- The booklet must indicate which stakeholders are part of a logistics solution so that they know they know who to cooperate with. (Non-functional requirement)

CHAPTER 6: DESIGN REQUIREMENTS

This chapter has the goal to explain how the analysis made in previous chapters has an impact on the product's design. The basic design cycle (Roozenburg & Eekels, 1995) has been adapted to apply to the design in two ways. The first is to design the feasible logistics solutions and the second is to design the booklet's lay-out of communicating the content of those logistics solutions.

There are two types of design requirements: functional and non-functional. A functional requirement is that the product enables the users to accomplish their tasks thus what the guide is supposed to do. A non-functional requirement is how the product must behave and establish constraints of its functionality.

6.1 FEASIBLE LOGISTICS SOLUTIONS DESIGN REQUIREMENTS

The following feasible logistics solutions design requirements have been found in the problem analysis of Chapter 3: Small-scale construction projects' characteristics, Chapter 4: Construction logistics' characteristics, Chapter 5: Stakeholders' objectives and roles and Appendix IX.

Functional design requirements for feasible logistics solutions:

1. Logistic(s) solutions must decrease the emissions caused by transport. (1.1 Problem statement)
2. Logistic(s) solutions must increase the load factor of construction logistics' transport. (1.3 Scope and deliverable)
3. Micro logistics solutions must allow contractors to drive to multiple locations during the day. (Chapter 3: Small-scale construction projects' characteristics)
4. Logistics solutions must be generic to be applied to a large variety of projects and coherent materials. (Chapter 3: Small-scale construction projects' characteristics)
5. Logistics solution(s) must give alternatives for the use of delivery vans. (Chapter 4: Construction logistics' characteristics)
6. Logistics solution(s) must be applicable for personnel, materials, tools and heavy equipment transport movements and indicate the solutions separately. (Chapter 4: Construction logistics' characteristics)
7. Logistics solution(s) must deal with the presence of necessary tools at the construction site. (Chapter 4: Construction logistics' characteristics)
8. Logistics solution(s) for materials must make use of hubs. (Chapter 4: Construction logistics' characteristics)
9. Logistics solution(s) must allow contractors to have the materials delivered rather than picked up. (Chapter 4: Construction logistics' characteristics)
10. Logistics solution(s) must propose distribution solutions to allow standardizing of materials. (Chapter 5: Stakeholders' objectives and roles)
11. Logistics solution(s) must help the subcontractors to be more supportive. (Chapter 5: Stakeholders' objectives and roles)
12. Carpooling costs need to be organized by the main contractor. (Appendix IX)
13. Municipality must issue a permit for minicontainers. (Appendix IX)
14. A clear overview must be present of who is going to pay for runners. (Appendix IX)
15. A hub must be close enough to the construction site. (Appendix IX)

16. Smart return must have good communication and arrangements between contractors, transporters and waste processors. (Appendix IX)
17. Bundling and last mile delivery of materials must be performed by an external party instead of a competitor. (Appendix IX)
18. Material data must have specifications on volume, length sizes and stackability to allow bundling. (Appendix IX)
19. The business model of rush orders must be performed by a different stakeholder than wholesalers. (Appendix IX)

Non-functional design requirements for feasible logistics solutions:

1. Logistics solutions must focus on freelancers and SMEs separately. (Chapter 3: Small-scale construction projects' characteristics)
2. Logistics solution(s) for heavy equipment in renovation projects are of less importance. (Chapter 4: Construction logistics' characteristics)
3. Logistics solution(s) for tools are of high importance. (Chapter 4: Construction logistics' characteristics)
4. Logistics solution(s) must focus initially on electric trucks as ZE alternative. (Chapter 4: Construction logistics' characteristics)
5. Logistics solution(s) must explain the difficult transport flows where exemptions should be made if ZE logistics is infeasible. (Chapter 4: Construction logistics' characteristics)
6. Logistics solution(s) must focus on completion construction transport movements. (Chapter 4: Construction logistics' characteristics)
7. Logistics solution(s) for waste must focus on combining delivery of materials with returning waste. (Chapter 4: Construction logistics' characteristics)
8. Logistic(s) solutions must deal with the limited space available at a construction site. (Chapter 4: Construction logistics' characteristics)
9. Micro logistics solutions will not make use of a CCC (Chapter 4: Construction logistics' characteristics)
10. Prefab can only be applied in medium sized construction projects. (Appendix IX)
11. Building tickets can only be applied for medium renovation and new construction projects. (Appendix IX)
12. Transport over water can only be applied for medium renovation and new construction projects. (Appendix IX)
13. Transport over water only feasible if construction site is close to water. (Appendix IX)
14. Carpooling is not possible for subcontractors for micro construction projects. (Appendix IX)
15. BIM can only be applied on new construction projects. (Appendix IX)
16. Runners can best be applied in small and medium sized construction projects. (Appendix IX)

These requirements are the foundation of what the logistics solution must contribute to and how the solutions must reach their goals. The numbers of the requirements are given in Table 13, Table 14, Table 15 and Table 16 to each logistics solution on which the requirement applies. The functional requirements 4, 5, 6 and 9 and non-functional requirements 2 and 6 are not directly but indirectly used in the synthesis of the feasible logistics solutions. Hence, these requirements are not represented in the tables.

The logistics solutions are either coming from logistics solutions found in literature or based on problem analysis of current logistics structures (Chapter 4: Construction logistics' characteristics) and brainstorm sessions. It can also be derived from a combination of both where literature has been used

as an initial set-up of logistics solution and that the problem analysis alters the solution to fit for small-scale construction projects. The table below describes the sources of the logistics solutions. The logistics solutions that only have 'design requirements of problem analysis' as source are derived from brainstorm sessions with people at TNO and from the interviews.

Table 12: Sources of logistics solutions

Logistics solution	Source
Carpooling	Based on literature (see Table 21) (Van Merriënboer, Vrijhoef, Ludema, & De Vries, 2013; De Bes, et al., 2018; Klerks, et al., 2012)
Cargo bike for contractor	Based on literature (De Leeuw, 2019) and on design requirements of problem analysis
Own ZE vehicle	Based on literature (see Table 21) (De Bes, et al., 2018) and on design requirements of problem analysis
Minicontainer	Based on literature (see Table 21) (Klerks, et al., 2012) and on design requirements of problem analysis
Decoupling point	Based on literature (see Table 21) (Klerks, et al., 2012) and on design requirements of problem analysis
Shuttle bus	Based on literature (see Table 21) (Van Merriënboer, Vrijhoef, Ludema, & De Vries, 2013; De Bes, et al., 2018; Klerks, et al., 2012) and on design requirements of problem analysis
Region manager	Based on literature (see Table 21) (Van Merriënboer, Vrijhoef, Ludema, & De Vries, 2013; Klerks, et al., 2012) and on design requirements of problem analysis
Smart return	Literature (see Table 21) (De Bes, et al., 2018)
Runners	Literature (see Table 21) (De Bes, et al., 2018)
Waiting area for deliveries	Literature (see Table 21) (De Bes, et al., 2018)
BIM	Literature (see Table 21) (Van Merriënboer & Ludema, 2016)
CCC	Literature (see Table 21) (Van Merriënboer, Vrijhoef, Ludema, & De Vries, 2013; De Bes, et al., 2018)
Transport over water	Literature (see Table 21) (Van Merriënboer, Vrijhoef, Ludema, & De Vries, 2013; De Bes, et al., 2018; Klerks, et al., 2012)
Prefab	Literature (see Table 21) (Van Merriënboer, Vrijhoef, Ludema, & De Vries, 2013; De Bes, et al., 2018; Klerks, et al., 2012)
Building tickets	Literature (see Table 21) (Van Merriënboer, Vrijhoef, Ludema, & De Vries, 2013; De Bes, et al., 2018)
Microhub	Design requirements of problem analysis
Mobile hub	Design requirements of problem analysis
Combining with other sectors	Design requirements of problem analysis
Trolley	Design requirements of problem analysis
Main contractor's tools	Design requirements of problem analysis
Locker	Design requirements of problem analysis

6.2 BOOKLET DESIGN REQUIREMENTS

The functional requirements are derived from the 1.1 Problem statement, 1.3 Scope and deliverable, 2.1 Thesis project objective and Appendix IX.

1. The product must make the stakeholders aware about the upcoming ZE zones. (1.1 Problem statement)
2. The product must contribute to less transport movements made by the construction sector. (1.1 Problem statement)
3. The product must contribute to less emissions made by the construction sector. (1.1 Problem statement)
4. The product must provide a list of feasible logistics solutions that can be applied in small-scale construction projects. (2.1 Thesis project objective)
5. The product must support collaborations between stakeholders. (1.3 Scope and deliverable)
6. The booklet must explain the costs and benefits of each logistics solution. (Appendix IX)
7. The booklet must give the requirements necessary to adopt a logistics solution. (Appendix IX)
8. The product must indicate at what time stakeholders should start organizing the logistics solution. (Appendix IX)

The non-functional requirements are derived from 1.3 Scope and deliverable, 2.1 Thesis project objective, Chapter 3: Small-scale construction projects' characteristics, Chapter 4: Construction logistics' characteristics and Chapter 5: Stakeholders' objectives and roles.

1. The product must focus on projects executed by SMEs. (1.3 Scope and deliverable)
2. The product must focus on the 30-40 municipalities in the Netherlands where the ZE zones will be established. (2.1 Thesis project objective)
3. The product must separate logistics solutions on micro, small and medium sized construction projects. (Chapter 3: Small-scale construction projects' characteristics)
4. The product must focus separate renovation projects and new construction. (Chapter 3: Small-scale construction projects' characteristics)
5. The product must focus mostly on renovation projects. (Chapter 3: Small-scale construction projects' characteristics
6. The product must address the urgency of the problem. (Chapter 4: Construction logistics' characteristics)
7. The product must categorize logistics solutions on personnel, material, tools and heavy equipment. (Chapter 4: Construction logistics' characteristics)
8. The product's target audience are the key players and the context setters: contractors, transporters, suppliers and municipalities. (Chapter 5: Stakeholders' objectives and roles)
9. The product must indicate which stakeholders are part of a logistics solution so that they know they know who to cooperate with. (Chapter 5: Stakeholders' objectives and roles)

Next to functional and non-functional requirements, there are also some design principles to make the guide as effective as possible. Chamorro-Koc et al. (2008) identified four sources of human experience influencing people's understanding of product usability: familiarity, episodic experience, experience from cultural background and experience from an expert domain. Familiarity with products that the users know before, makes it easier to understand. Episodic experience relies on the knowledge of the product's intended use or description based and the physical context of the product's use. Cultural background means that the user must understand the product's intended use. The experience from expert domain leads to that the user is only interested in the functionality and not the detailed aspects of the solution. The four sources Chamorro-Koc et al. (2008) have led to the following design principles that the product must have incorporated.

1. The product must be self-explanatory.
2. The product must be understandable by the user with a design that they are familiar with.
3. The product must limit the options to what the user need.
4. The product must chunk down the information into logical groups.
5. The product must not go into too much detail.
6. The product must not have abbreviations.
7. The product must be printable.

Next to the design principles related to the product are design principles related to the aesthetics. Stevenson (2020) came up with five of those design principles: alignments, repetition, contrast, hierarchy and balance. These five principles have been used by the lay-out and creating the design.

CHAPTER 7: FEASIBLE LOGISTICS SOLUTIONS

SQ 4: What are feasible logistics solutions to generate transport efficiency and sustainability?

All stakeholders might have experiences and do have an opinion about the logistics solutions for small-scale construction projects. Firstly, this chapter will evaluate the interviewed stakeholders about their opinion and experiences about logistics solutions. The stakeholders' opinions and experiences are useful to know what they like about certain logistics solutions and what barriers are preventing the stakeholders from using them. Secondly, the feasible logistics solutions will be allocated on micro, small and medium-sized renovation construction projects and on new construction projects. Thirdly, a timeline will be constructed that indicates in which phase a logistics solution must be considered to implement. Fourthly, the vehicle applications that are more difficult or less urgent to switch to ZE will be discussed. Fifthly, the solutions are put into practice where three scenarios and a plan of action will be given. Lastly, a conclusion will be made to answer subquestion 4.

7.1 STAKEHOLDERS' PERCEPTIONS LOGISTICS SOLUTIONS

The summary of what the stakeholders have told about logistics solutions can be found in Appendix IX. The interviewed stakeholders are listed in Table 1 and the interview protocol to gather these perceptions is in Appendix III. The stakeholders have been anonymized to protect their privacy to allow this thesis project to be shared. Those parts of the interviews gave information about several requirements, costs and benefits a logistics solution has. That information is translated into a list of design requirements for the logistics solutions (see Chapter 6: Design requirements). However, interviews will not result in all requirements, costs and benefits. Therefore, a more in-depth analysis is required. This is performed in paragraphs 7.2.1 Micro renovation projects, 7.2.2 Small renovation projects, 7.2.3 Medium renovation projects, 7.2.4 New construction projects and 7.2.5 Costs and benefits logistics solutions.

7.2 ALLOCATION OF FEASIBLE LOGISTICS SOLUTIONS

The logistics solutions depend on the type of transport if it is either material, equipment or person transport and in depends on what vehicle is used. These three transport types are all transported by a specified transporter. Those in charge of the transport and which vehicles are used are visualized in Figure 18.

The logistics differences between renovation and new construction are large. The logistics solutions found in literature (Appendix II) were tested on mostly large-sized and to a lesser extent medium-sized projects. The results of the first three subquestions have led to how the small-scale construction projects are logistically organized. Based on the distinction of micro, small and medium projects, feasible logistics solutions are proposed in this chapter.

The micro, small and medium projects will be applied to renovation projects. New construction projects differ too much from renovation projects that feasible logistics solutions are provided to this type of construction by itself in 7.2.4 New construction. Urban area construction projects usually are renovation projects because the buildings are already there. New construction is less present and if

there is new construction, it will be mostly large construction projects and sometimes executed by SMEs.

The logistics solutions in paragraphs 7.2.1 Micro renovation projects, 7.2.2 Small renovation projects, 7.2.3 Medium renovation projects and 7.2.4 New construction projects are based on the representation of the construction logistics' transport movements visualized earlier (see Figure 18). Those movements can be specified and appointed to the responsible stakeholders that take care of the transport. The three main groups of transport movements are personnel, material and equipment (tools and heavy equipment). More specified within these groups is that personnel and tools are separated on freelancers and SMEs. The term freelancer is used because the share of freelancers in the construction sector is 83.7% (see Figure 8). However, small contractors are also part of this group. These freelancers and small contractors are mostly executing their work as subcontractors. This setup of on what a logistics solution will be applied is used in the next four paragraphs (7.2.1 Micro renovation projects, 7.2.2 Small renovation projects, 7.2.3 Medium renovation projects and 7.2.4 New construction projects).

7.2.1 MICRO RENOVATION PROJECTS

First, a brief explanation will be given what micro renovation projects are and afterward, the allocation of solutions for micro renovation projects will be discussed. The size of a micro project is less than 150 m^2 GFA (and below €0.3 mln construction costs), thus a private house. The contractors working on these projects are mostly freelancers and sometimes an SME. The personnel transport for micro renovation projects is difficult to manage with the coming ZE zones. Freelancers can have multiple projects during a single day. Hence, they need to drive during the day to different locations. Personnel transport works best if they can park the car at the edge of the ZE zone and from that place be transported to their destination. The material transport can either be picked up or be delivered. The ratio between pick-up and delivery is 50/50% according to the interviews. Heavy equipment is not or occasionally used for micro renovation projects (scaffolding/mobile toilet).

The feasible logistics solutions for micro renovation projects are found based on an analysis of the type of transport movement and what vehicles are used. All the feasible solutions are shown in Figure 24. There are solutions that are shown multiple times on the right-hand side because the solution can be applied for different transports. A ZE vehicle can be owned by both freelancers and SME contractors but the requirements for this logistics solution are different. An own electric vehicle provides the freelancers' freedom to move wherever and whenever they want within urban areas after the ZE zones are initiated. Freelancers mostly have multiple jobs at different locations during a day and their own tools can be taken along in the ZE vehicles, which makes this the best feasible logistics solution for personnel transport.

Cargo bikes can also bring personnel and tools to the construction site and to multiple locations during one day but are unusual for contractors to use. Public transport is useful to transport personnel to the destination but in that case, there is a problem with how the tools can be brought with them. Main contractor's tools can assist with that problem where the main contractor will take care of the necessary tools present at the location. The material transport logistics solutions are limited to microhub, mobile hub, combining with other sectors and smart return whereas small and medium renovation projects have more logistics solutions for material transport. Smart return is another type of material transport solution because it is for waste return flow and not for material transport towards the construction site. The explanation and requirements for the solutions are represented in Table 13.

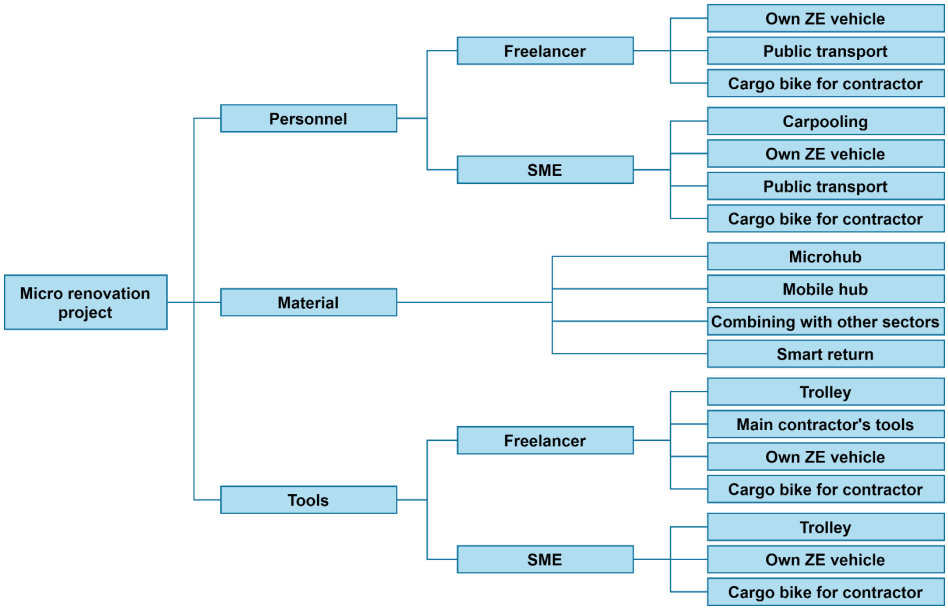


Figure 24: Overview of feasible logistics solutions for micro renovation projects

Table 13: Feasible logistics solutions for micro renovation projects. FR = functional requirement and NFR = non-functional requirement (for requirements see Chapter 6: Design requirements)

Feasible logistics solution	Found requirements leading to this logistics solution	Explanation	Requirements
Own ZE vehicle (freelancer)	FR: 1, 3, 5 NFR: 1	The freelancer has an own ZE vehicle that he uses to go to the construction site and he can bring his own tools.	• Financial support to purchase the ZE vehicle. • Charging infrastructure throughout the country needs to assist that charging while at work is possible. • High density of charging stations in urban area.
Public transport (freelancer)	FR: 1, 3, 5 NFR: 1	The freelancers can either take public transport from home towards the location or from the city's edge.	• Good public transport connections within the ZE zone. Otherwise it is too complicated for them to move to different locations and the travel time is too large. • Locations at the city's edge must be organized in a way that they can park their vehicle and walk to the public transport. • The necessary tools need to be provided on the location or the freelancer needs to carry it with him. • Behavioral change of contractors. • Material transport must all be delivered by wholesaler/transporter. • Contractors must plan their work and procurement. • Public transport travel time between projects must not exceed own vehicle travel time significantly.
Cargo bike for contractor	FR: 1, 3, 5	With a cargo bike (can be electric) you can cycle from the city's edge to the construction site. The contractor's vehicle can be parked at the bicycle location. It is also possible to take an ordinary electric bike in case the tools and materials are on the construction site. Recently, large contractor BAM already donated five e-bikes to Bouwhub Amsterdam (De Leeuw, 2019).	• Organization of the cargo bike business model. • Behavioral change of contractors. • Tools and materials need to fit in cargo bike if the tools and materials need to be taken with them.

Carpooling (SME)	FR: 1, 5, 12 NFR: 14	Personnel of SME contractors are colleagues of each other and they can share the use of their vehicle with carpooling. The occupancy rate of the vehicle increases which results in fewer transport movements. Carpooling is impossible for freelancer contractors because they are the only one in their enterprise and can have multiple jobs during a day.	• Planning of work performed at one single location needs to be adjusted in order that all personnel driving together at the project have enough tasks to perform during the day. • The delivery van needs to be ZE from 2025. • Personnel needs to live close enough to each other or live on the way to the location.
Own ZE vehicle (SME)	FR: 1, 3, 5 NFR: 1	The SME main contractor has his own vehicle fleet. This fleet consists out of multiple delivery vans of different ages. It is not necessary to have a full ZE vehicle fleet. A part of the fleet will do. Furthermore, the fleet can be expanded with ZE alternatives such as electric scooters, (cargo)bikes or a regular ZE passenger car.	• Financial support to purchase the ZE vehicle. • Planning of ZE vehicle use. • Loading infrastructure at the contractor's establishment to charge the vehicles outside working time. • High density of charging stations in urban area.
Public transport (SME)	FR: 1, 3, 5 NFR: 1	SME contractors' personnel can either take public transport from home towards the location or from the city's edge.	• Good public transport connections within the ZE zones. • Material transport must all be delivered by wholesaler/transporter. • Behavioral change of contractors.
Microhub	FR: 1, 8, 10, 15, 17, 18	A microhub is a location with space for completion construction materials and not for large heavy materials. This hub acts as a decoupling point between construction sites and suppliers. The last mile can then be transported zero-emission by electric vehicles or a cargo bike or contractors can pick it up themselves.	• Contractors must plan their work and procurement. • Organization of the microhub. • Tactical location for an establishment. • Order handling IT system needs to know when an order can make use of the microhub in terms of volume, length sizes and stackability of the orders' products. • Universal materials data usage. • Material transport must all be delivered by wholesaler/transporter. • High use of the microhub to increase load factor of last mile bundle.
Mobile hub	FR: 1, 2, 8, 17, 18	A mobile hub is a large vehicle that picks up from various suppliers and supplies to multiple construction projects.	• Contractors must plan their work and procurement. • The organization of the mobile hub. • Order handling IT system needs to know when an order can make use of the mobile hub in terms of volume, length sizes and stackability of the orders' products. • Universal materials data usage. • Material transport must all be delivered by wholesaler/transporter.
Combining with other sectors	FR: 1, 2, 19	Generally, the materials for micro projects are small. That is why it is possible to combine with the logistics of other sectors. Last mile can be performed with cargo bikes or electric vehicles.	• Materials need to fit in the vehicle. • Order handling IT system needs to know when an order can make use of the mobile hub in terms of volume, length sizes and stackability of the orders' products. • Universal materials data usage.
Smart return	FR: 1, 2, 16 NFR: 7, 8	The loader crane truck can be used directly after the supply of materials to take back waste or incorrectly delivered materials.	• Communication and collaboration between the waste transporter and contractors. The contractor needs to share that they have full big bags or waste containers that can be taken away. • The vehicle used for supply needs to be able to transport the waste storage.
Trolley (freelancer)	FR: 7 NFR: 1, 3	A trolley can be used to store all the tools needed. The contractor is not limited in using a delivery van to carry his tools.	• Trolley needs to be able to store all the necessary tools. • Contractor should think better about which tools are needed in a day. • Behavioral change of contractors.
Main contractor's tools	FR: 7, 11 NFR: 3	The main contractor provides his tools to his subcontractors. Freelancers are more flexible if they only have to bring their own small tools. Large tools such as a circular saw table must be available on site.	• Main contractor willing to share his tools. • Trust between main contractor and the freelancers.

Own ZE vehicle (tools freelancer)	FR: 5, 7 NFR: 1, 3	Tools transport is possible without problems if a contractor owns a zero-emission vehicle.	• Same as for personnel transport (*see 7.2.1 Micro renovation projects: Contractor (freelancer) → Personnel → Own ZE vehicle*).
Trolley (SME)	FR: 7 NFR: 1, 3	The tools needed for SME contractors' personnel is even less because the personnel can combine their tools. A trolley is a good solution so that they can carry their tools along.	• Same as for personnel transport (*see 7.2.1 Micro renovation projects: Contractor (SME) → Personnel → Own ZE vehicle*).
Own ZE vehicle (tools SME)	FR: 5, 7 NFR: 1, 3	There are no problems to transport the tools in case that the SME contractor owns a ZE delivery van.	• Same as for personnel transport (*see 7.2.1 Micro renovation projects: Contractor (SME) → Personnel → Own ZE vehicle*).

7.2.2 SMALL RENOVATION PROJECTS

First, a brief explanation will be given what small renovation projects are and afterward, the allocation of logistics solutions for small renovation projects will be discussed. The size of a small construction project is between 150 m^2 and 1,000 m^2 GFA (and between €0.3 mln and €3 mln construction costs). Mostly, these projects are apartment buildings or linked houses. The main contractors are SME contractors. The people who carry out the project are the SME contractors' own personnel and hired subcontractors. They only are working at one small project during a day and not multiple different projects thus intermediate personnel transport movements are absent. The type of material transport is equivalent to micro projects. The quantity of the materials is higher. Heavy equipment is used occasionally for small renovation projects.

An overview of feasible logistics solutions has been made just as for micro renovation projects as shown in Figure 25. There are some differences and similarities with micro renovation projects. The solutions for personnel transport are now the same for freelancers and SME contractors because the construction projects are now large enough that contractors will work during an entire day at the location and do not need to move to different locations during the day. This also allows a shuttle bus as a new alternative for personnel transport but also to use a locker for tools. Material transport solutions are a lot different than for micro projects. The total construction costs and quantity of materials used increase which allows these new logistics solutions to be feasible. A mobile hub can be applied on larger than micro renovation projects but has the restriction that the materials must be small and light to be combinable. Furthermore, heavy equipment is now used more than for micro renovation projects and needs a logistics solution. The only found feasible logistics solution is the use of a decoupling point. There are multiple logistics solutions that fit for both micro as small projects. If the application of the logistics solution is identical to a previously described logistics solution, it will be left out of the Table 14 to maintain a clear overview. All the feasible logistics solutions that are specific to small renovation projects and not discussed earlier are represented in Table 14.

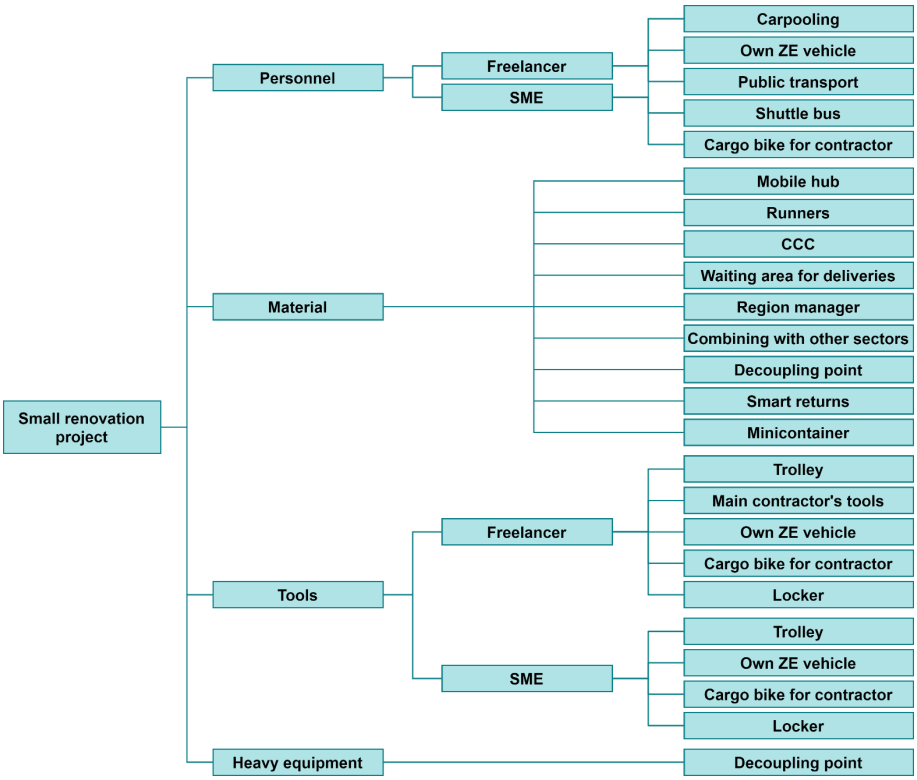


Figure 25: Overview of feasible logistics solutions for small renovation projects

Table 14: Feasible logistics solutions for small renovation projects. FR = functional requirement and NFR = non-functional requirement (for requirements see Chapter 6: Design requirements)

Feasible logistic solution	Found requirements leading to this logistics solution	Explanation	Requirements
Own ZE vehicle (freelancer small project)	FR: 1, 5 NFR: 1	An own electric vehicle provides the freelancers freedom to move wherever and whenever they want within urban areas after the ZE zones are initiated.	Same as for micro projects (*see 7.2.1 Micro renovation projects: Contractor (freelancer) → Personnel → Own ZE vehicle*).
Public transport (freelancer small project)	FR: 1, 5 NFR: 1	The freelancers can either take public transport from home towards the location or from the city's edge.	Same as for micro projects (*see 7.2.1 Micro renovation projects: Contractor (freelancer) → Personnel → Public transport*).
Carpooling (freelancer)	FR: 1, 5, 12 NFR: 1, 14	Freelancers are busy with one project during a day thus they can join other contractors to the location.	• Communication between the subcontractor and main contractor for the set-up of carpooling. • The delivery van needs to be ZE from 2025. • Personnel needs to live close enough to each other or on the way to the location.
Shuttle bus	FR: 5, 11	A shuttle bus (possibly electric) drives from the city's edge to the construction sites. The more people who use a shuttle bus service, the less time it will take to arrive at the destination because the shuttle buses can be grouped by neighborhoods.	• Location at the city's edge to park the car. Can be a parking lot (P+R) or a wholesaler's establishment. • Organization of the shuttle bus. • Main contractor must communicate that this is an option to the freelancer subcontractors and how they can make use of it.

			• Contractor must move his equipment easily from own truck to the shuttle bus. • Tools need to fit in the shuttle bus.
Runners	FR: 11, 14 NFR: 16	Runners can move the materials to the exact location where they are needed. The person responsible for transport or the contractor himself can do this. Contractors do not longer have to search for and carry the materials themselves and can work directly with the materials when they arrive at the location.	• Main contractor must indicate which materials are needed on which location at the construction site. • Contractors must plan their work and procurement.
CCC	FR: 1, 2, 8, 10, 15, 17, 18 NFR: 8, 9	All material transport uses the construction consolidation center to store the material at the city's edge. Afterward, the materials will be bundled and delivered to the construction sites. An additional service can be a place for contractors to park their car and be transported from the construction consolidation center to the construction site.	• Procurement must be performed centralized. • Contractors must plan their work and procurement.
Waiting area for deliveries	FR: 1 NFR: 8	Trucks are waiting on the city's edge and wait for a sign to deliver the materials. This logistics solution is advantageous if limited storage space is available on site.	• Available location on city's edge close to the construction site where vehicle can be parked for free. • Planning by main contractor. • The driver is willing to wait. • Truck is dedicated for the construction project and not for other projects. Otherwise, conflicts will arise to deliver other projects.
Decoupling point	FR: 1, 8, 17 NFR: 4	Materials are delivered on the city's edge and loaded directly with outgoing materials without intermediate storage. Trailers can be disconnected from tractors and the last mile can be driven with a zero-emission tractor. Construction consolidation centers can offer this as a service to transport last mile zero-emission.	• Decoupling point needs to have ZE trucks and tractors available. • IT logistics system needed. The decoupling point's organizer needs to incorporate this in their operations. • Charging infrastructure available at decoupling locations. • Technologically feasible to decouple and couple trailer.
Minicontainer	FR: 7, 8, 13 NFR: 3, 8	A small container dedicated to a construction project. Projects have temporary housing and waste containers, usually in parking lots and this minicontainer can be added to this list of temporary housing. Tools can also be stored in the minicontainer.	• Materials must fit in the container. • Enough space available in public space to place the container. • The supplier and the contractor need to have a key to open the container. • The municipality must give a permit.
Region manager	FR: 1, 18	An independent person who knows the projects in a city and can manage coordination between the projects. The supply of materials can be synchronized and delivered together in a neighborhood.	• Contractors must plan their work and procurement. • Organization of the region manager. • Contractors need to share information about their orders. • Different suppliers need to be bundled together. • Order handling IT system needs to know when an order can make use of the mobile hub in terms of volume, length sizes and stackability of the orders' products. • Universal materials data usage. • Material transport must all be delivered by wholesaler/transporter.
Locker	FR: 7 NFR: 3	The necessary tools can be stored and locked at the construction site.	• Main contractor's personnel and subcontractors must not have multiple projects during one day. • Main contractor must provide and manage the lockers.
Decoupling point (heavy equipment	FR: 1, 8 NFR: 4	Heavy equipment is often placed on a trailer. A decoupling point allows the last mile to be ZE.	• Heavy equipment can fit on a trailer. • Decoupling point needs to have ZE trucks and tractors available. • IT logistics system needed. The decoupling point's organizer needs to incorporate this in their operations.

			• Charging infrastructure available at decoupling locations. • Technologically feasible to decouple and couple trailer.

7.2.3 MEDIUM RENOVATION PROJECTS

First, a brief explanation will be given what medium renovation projects are and afterward, the allocation of solutions for medium renovation projects will be discussed. The size of a medium renovation project is between 1,000 m^2 and 10,000 m^2 GFA (and between €3 mln and €20 mln construction costs). These are larger buildings close to each other or large apartment building blocks. The transformation of non-residential buildings to residential buildings is a development that is increasing these years because of the residential buildings' shortage. The main contractors are SME contractors that subcontract smaller SME contractors and freelancers. The material used is similar to micro and small renovation projects but may involve some large heavy materials. The quantity of materials is higher than for small renovation projects (thus also for micro renovation projects). There are reoccurring logistics solutions equivalent to micro and small renovation projects. If the application of the logistics solution is identical to a previously described logistics solution, it will be left out to maintain a clear overview.

The logistics solutions for medium renovation projects are almost similar to small renovation projects (see Figure 26). The only added logistics solutions are represented and discussed in Table 15.

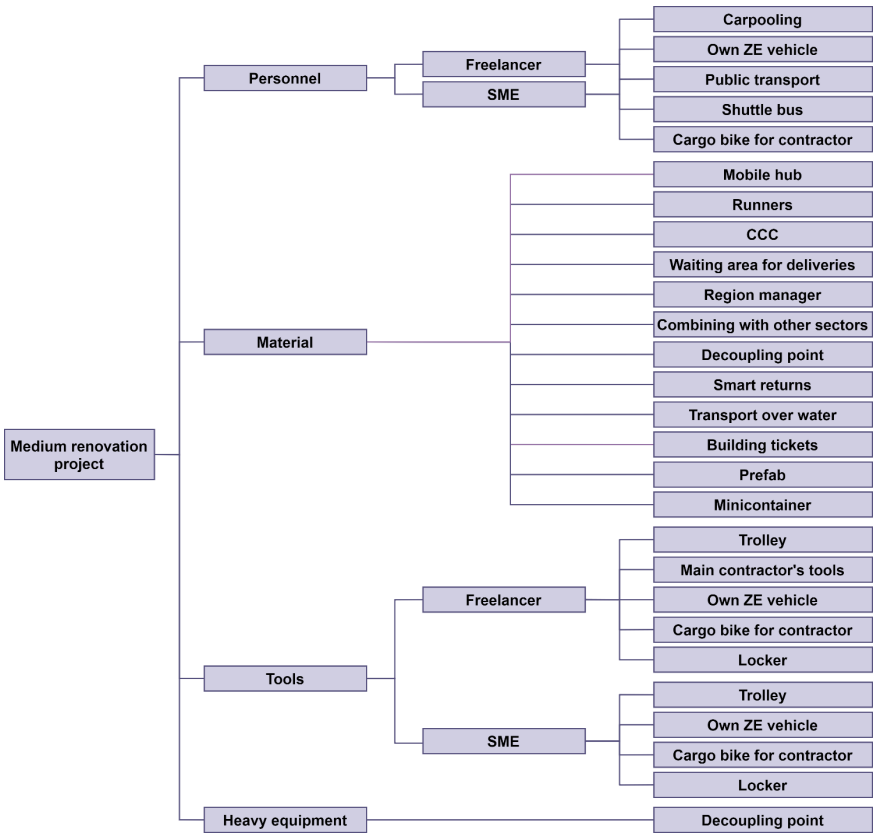


Figure 26: Overview of feasible logistics solutions for medium renovation projects

Table 15: Feasible logistics solutions for medium renovation projects (for requirements see Chapter 6: Design requirements)

Feasible logistic solution	Found requirements leading to this logistics solution	Explanation	Requirements
CCC (medium project)	FR: 1, 2, 8, 10, 15, 17, 18 NFR: 8, 9	Research has been applied on the use of a CCC for a medium renovation project. An upscale of combining a CCC with similar projects results in significant fewer transport movements with only between 0.04% - 1.19% additional costs (Dijkmans, et al., 2014). A stimulation of the use of a CCC results in economies of scales.	• Procurement must be performed centralized. Subcontractors purchase their own materials but need to deliver it at the CCC who will transport it to the site afterward. • Contractors must plan their work and procurement.
Transport over water	FR: 1 NFR: 8, 12, 13	A change in modality from road to water. The last mile in urban areas can be transported on water. A common practice is that transport over water is combined with a CCC for optimal load factor of last mile deliveries.	• Construction site must be close to water. • Additional actions are needed to hoist the materials from the boat to the building. • Boats must be allowed to dock close to the location.
Building tickets	NFR: 8, 10	The supplier is given a signal from the main contractor at what time and which materials are needed in the main contractor's planning. This works in combination with a construction consolidation center or waiting area for deliveries.	• Contractors must plan their work and procurement. • Communication between the main contractor and supplier that an approval is given when the supplier may deliver the materials. • Truck is dedicated for the construction project and not for other projects. Otherwise, conflicts will arise to deliver other projects.
Prefab	FR: 1, 2 NFR: 10	A part of the construction project is prefabricated before going to the construction site. Medium-sized renovation projects are large enough that prefab can be a feasible solution.	• Producer must be capable of producing the materials prefab. • The materials must fit in a truck or on a trailer. • The materials need to be able to be placed at the right location on the construction site.

7.2.4 NEW CONSTRUCTION PROJECTS

The thesis project focuses on small-scale construction projects. The conducted interviews revealed that SMEs are mostly involved in renovation and maintenance and some are also involved in new construction. New construction projects are separated from renovation projects because there are other transport movements involved. Shell construction is present in new construction whereas renovation only involves completion construction. However, almost all logistics solutions that are also applicable for new construction are already discussed in previous paragraphs. Hence, the logistics solutions to medium renovation projects also apply to new construction projects (as shown in Figure 26). The only additional logistics solution is BIM (see Table 16). Furthermore, logistics are better planned than for renovation projects. The projects are much more process-oriented. Detailed planning for construction is necessary to meet the permits. Renovation projects are diverse and less process-oriented. The more process-oriented a project is, the better its schedule and material requirements will be. There is no distinction in sizes for new construction projects because the new logistics solution found in this paragraph is applicable to all sizes. Furthermore, the logistics solutions feasible for medium renovation projects can all be applied to all sizes of new construction because the quantity of materials is high.

Table 16: Feasible logistics solutions for new construction projects

Feasible logistic solution	Found requirements leading to this logistics solution	Explanation	Requirements
BIM	1, 19, 30	The construction work is digitalized in a 3D model. The work to be performed is digitalized and so are the required materials. The construction work can be combined with the scheduled required materials. The flow of materials can be coordinated in this way to have a just-in-time supply. Furthermore, the materials can be bundled better because the entire process is placed in the model.	• Architect must be familiar with BIM. • Logistics coordinator to communicate BIM's material output with the suppliers.

7.2.5 COSTS AND BENEFITS LOGISTICS SOLUTIONS

All logistics solutions discussed in previous paragraphs have costs and benefits. The costs are the barriers to why a logistics solution is hard to implement and the benefits are the reasons why a logistics solution should be implemented. The logistics solutions can be stimulated by technological developments and regulations. The ZE zone is such regulation that will cause a large impact that will force everybody to act. Technological developments can reduce the costs in the future. An overview of all costs and benefits of the feasible logistics solutions is represented below in Table 17.

Table 17: Costs and benefits of logistics solutions

Logistics solution	Costs	Benefits
Own ZE vehicle	• High purchase price • Limited range • Dependent on charging infrastructure	• Possibility to enter ZE zones • No emissions (except PM) • Flexible to travel between projects • Less material planning required • Less maintenance costs • Tools storage space
Public transport	• Additional travel time • Walking to project • Inflexible to travel between projects • Inflexible to purchase materials • Limited amount of own tools	• Possibility to enter ZE zones • Reduced emissions • No parking costs • No additional transport movements
Carpooling	• Additional travel time • Inflexible to travel between projects • Inflexible to purchase materials • Difficult during epidemics	• Possibility to enter ZE zones, (if vehicle is ZE) • No emissions except PM (if vehicle is ZE) • Shared use of ZE (if vehicle is ZE) • Fewer transport movements • Shared parking costs • Shared transport costs
Shuttle bus	• Inflexible to travel between projects • Inflexible to purchase materials • Limited amount of own tools	• Possibility to enter ZE zones (if vehicle is ZE) • No emissions except PM (if vehicle is ZE) • Shared use of ZE (if vehicle is ZE) • Fewer transport movements • No parking costs
Cargo bike for contractor	• Limited amount of own tools • Unattractive in case of bad weather	• ZE transport • No parking costs • Flexible to travel between projects
Microhub	• Storage costs • Last mile delivery costs • No delivery by supplier's driver	• Fewer transport movements • Shared use of ZE (if last mile vehicle is ZE) • Possibility to supply in night
Mobile hub	• Last mile delivery costs • No delivery by supplier's driver	• Fewer transport movements • Shared use of ZE (if last mile vehicle is ZE)
Smart return	• Operational costs	• Fewer transport movements • Less waste at construction site • Less costs for road obstruction permits • More storage space
Runners	• Labor costs	• Increased work efficiency personnel • Lower hourly rates for runners than for contractors • Possibility for outside construction time delivery

CCC	• Storage costs • Operational costs	• Fewer transport movements • No emissions except PM (if last mile vehicle is ZE) • Shared use of ZE (if last mile vehicle is ZE) • Just-in-time deliveries
Minicontainer	• Costs for area in public space	• Fewer transport movements • Possibility to supply in night
Combining with other sectors	• Only small materials	• Fewer transport movements • Possibility to have rush orders • Shared use of ZE (if last mile vehicle is ZE)
Region manager	• Labor costs • Inflexible supply time slot	• Fewer transport movements
Waiting area for deliveries	• Waiting costs	• Just-in-time deliveries • Less traffic jams • Less nuisance
Decoupling point	• Operational costs • Extra last mile delivery costs • Additional travel time • No own driver for delivery	• ZE transport • No storage costs • Possibility to coordinate for just-in-time deliveries
Transport over water	• Operations to transport materials from water to land • Only possible for construction sites near water • Extra last mile delivery costs	• No transport movements on the road • Extra storage space • No sagging quays • More material supply for each movement
Prefab	• No client specifications • Extra costs in case of special transport	• Fewer transport movements • Shorter construction time at the site • High quality control
Building tickets	• Administrational effort • Wrong information on ticket in case of delay • Not always adhered to	• Just-in-time deliveries
BIM	• High architect costs • Additional design time	• Precise material requirement • Improved just-in-time deliveries • Less lead time at construction site • Less construction mistakes
Trolley	• Limited space	• Not dependent on own delivery van • Flexibility to move to different locations
Main contractor's tools	• Extra costs for main contractor • Possible theft	• Subcontractors not dependent on own tools • Possibility to share personnel transport • Shared use of tools
Locker	• Inflexible to work at multiple projects • Storage space	• No transport of tools • No theft

7.2.6 TIMELINE LOGISTICS SOLUTIONS

A construction project is composed of six phases (Koutsogiannis, 2020). These phases are applied to all construction projects even though their size, number of stakeholders involved, budget and delivery date may vary. The phases are required to understand the sequence of actions within a construction project to determine at what phase a logistics solution needs to start with the organization. The phases are concept of project, design, pre-construction, procurement, construction and post construction. Four out of six of these phases are used for the timeline shown in Figure 27. This timeline functions as a tool to know when stakeholders need to start organizing a logistics solution. The phases *concept of project* and *post-construction* phases do not have an added value for the timeline and have been left out of the timeline. Furthermore, the phase *before project* has been added. An own ZE vehicle and a trolley are logistics solutions that should be bought before a project. They do not have a direct connection with a construction project because they can use it for multiple or all construction projects. Several logistics solutions are only of use in the procurement phase and not in construction phase whereas others are of use in both procurement phase and construction phase.

There are three moments of a logistics solution during a construction project as visualized in Figure 27: start of logistics solution, organization of logistics solution and use of logistics solution. The start of a logistics solution is when the relevant stakeholders must begin with organizing the solution (green diamond). The organization is the time needed from organizing until it can be used (green arrow). The

use of the logistics solution can be applied to procurement and/or construction (blue arrow). The explanation of the logistics solutions and their application within the construction project is given in the explanation of the phases below Figure 27.

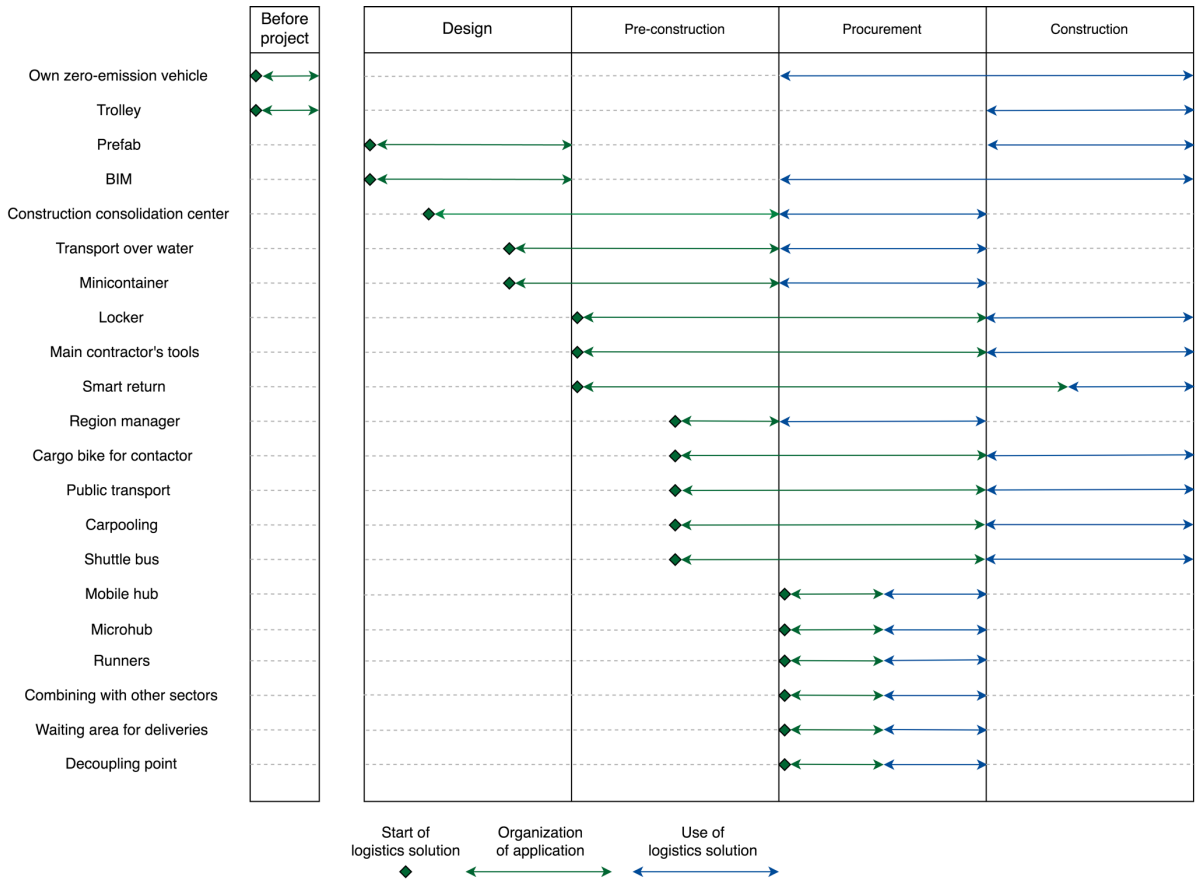


Figure 27: Timeline of logistics solutions

1. Concept of project

This is the project's start. A client has a desire to start a construction project and begins with conceptualizing his needs. The location with the right specifications is searched for in this phase. The duration differs and can take from a few days to a few months or more. The client communicates the budgetary and schedule constraints. Afterward, the site and soil will be surveyed such that the construction outline can be proposed and initial total construction costs can be estimated. Construction logistics are not yet part of the project during this phase.

2. Design

Usually, the bidding or tender process begins in the design phase. The architect will make sure that the regulations are met, that fits with the requirements of the client. Firstly, the programming and feasibility is to outline the objectives of the project. A general sketch of the building will be made. Secondly, the sketch will go more into detail in a schematic design. This includes the use of materials. Thirdly, the design development is the research of which equipment is needed and the costs related to the use of equipment and materials. The tender process is the selection of the main contractor. All contractors interested can issue their documentation. These tenders will be reviewed and the most promising ones will be interviewed. Finally, after contract negotiation, the contract documents are drawn up with final drawings and specifications.

In this phase, construction logistics are introduced in a project. First, the architect can choose to apply BIM (Building Information Model) or prefab. These solutions need to be started at the start of the design phase because it is the architect who makes the technical drawings. When the drawings have been completed, hubs can be organized. The use of a CCC needs to be organized as soon as possible because all material transport must flow through the CCC. The use of transport over water is location-dependent and requires a high amount of materials to be transported. Often, this logistics solution is combined with a CCC. If the location fits transport over water, the procurement of materials needs to be organized central to transport all the materials over water. A minicontainer is also location dependent whether it can fit within public space. Municipalities must agree on a minicontainer to be placed in public space. These logistics solutions need to start in the design phase because it is a part of the tender negotiation.

3. Pre-construction

The bidding is completed and the contractor is chosen. The contractor will compose a project team that will examine the construction site. Afterward, the municipality will review all plans and findings. In this phase, municipalities can set environmental requirements that might have an impact on the logistics structure of the construction project.

Several logistics solutions must start in this phase of a construction project. A locker and main contractor's tools must be organized at the start of the pre-construction phase because the project team will be composed in this phase. The hired subcontractors must know about if a locker or main contractor's tools will be applied in the construction project to organize their operations. Smart return is a collaboration of waste processors and suppliers. The main contractor must discuss with the waste processor the alternatives of waste storage and how these can be taken back more efficiently. This discussion will take place at the end of the design phase/beginning pre-construction phase. Later within the pre-construction phase, a region manager can determine if there are similar projects in the neighborhood in which supply of materials can be combined. Furthermore, the personnel transport must be organized after the project team has been composed. Hence, a cargo bike for contractor, public transport, carpooling and shuttle bus are halfway in the pre-construction phase.

4. Procurement

The construction can only start if the materials are available. The procurement is performed to collect the necessary materials, equipment and workforce. The main contractor and their subcontractors order their materials. This separation of procurement between the main and subcontractors is specific to small-scale projects. A main contractor hires his subcontractors on a task basis. The subcontractors are specialists in disciplines such as tiling, plastering or painting where they buy the materials that they need for the project.

When the materials are ordered, suppliers must communicate with each other if it is possible to combine transport to deliver to their customers. Therefore, the logistics solutions mobile hub, microhub and combining with other sectors must start at the beginning of the procurement phase. Runners must be organized by the suppliers (occasionally contractors themselves). The suppliers must evaluate the construction site and submitted orders to suggest to the main contractor to make use of runners. This evaluation must take place at the beginning of the procurement phase.

The use of logistics solutions starts in the procurement phase. The logistics solutions that can be used from the beginning of the phase are own ZE vehicle, cargo bike for contractor, BIM, CCC, transport

over water, minicontainer and region manager. The reason why these solutions can be used from the beginning of the procurement phase is that they already have been organized earlier. The other solutions that can be applied during the procurement phase but not from the beginning are mobile hub, microhub, runners, combining with other sectors, waiting area for deliveries and decoupling point. All these solutions can only be organized if contractors' orders have been placed at suppliers.

5. **Construction**

The construction starts with a meeting to ensure that everyone is on the same page when the construction starts. Topics generally discussed in this meeting are how to access the job site, quality control of the construction project, how and where to store materials and hours that everybody will be working.

Several logistics solutions are of use in this phase. The personnel transport and tools transport logistics solutions are applied during construction. These are own ZE vehicle, cargo bike for contractor, trolley, locker, main contractor's tools, public transport, carpooling and shuttle bus. Prefab leads to production before going to construction thus is of use during the construction phase. BIM is creating the design digitally and thus it can be exactly known which materials are needed at what time and therefore also of use during the procurement phase. Smart return is applied in the construction phase to take back waste. The blue arrow in Figure 27 does not start at the beginning of construction to visualize that it is about waste because waste is only present later in construction.

6. **Post-construction**

Before the project is completed three steps must be executed. First is the inspection and training. The inspection is to check if the building meets its requirements but it is not an extensive inspection because intermediary inspections check the quality during the project. Afterward, the client is trained on how to operate and maintain the building. Second is the owner occupancy. The client takes over the building and can use it. Third is the closure. This is the final step of the project. The project team needs to make sure that all contractual agreements are met. A post-project review helps to detect and explain unfinished tasks. There are no logistics operations applied during post-construction.

7.2.7 DIFFICULT ZE IMPLEMENTATION

The ZE zones require fundamental changes to the logistics structures in the construction sector. The transition to ZE is not always achievable for specific transport movements and the effort to switch to ZE can be too high.

The future technological developments are uncertain and according to Luman (2019), there probably will only be 3,500 battery-electric trucks available in 2030 (see Figure 15 in 4.1.2 Trucks zero-emission transition). Those trucks will be used for urban freight logistics but are less useful for the construction sector than for the retail sector. Supermarkets have detailed and consistent planning where the use of electric trucks are more efficient because their travel distance is known. The following transport movements are more difficult or less urgent to switch to ZE:

- Concrete mixer

The concrete mixer is dedicated to concrete and thus for new construction. Therefore, the load factor of the truck is always maximized because it cannot be combined with other supplies. The technological

development of availability and purchase costs of ZE concrete mixers should be monitored to evaluate if concrete material supply can be ZE in 2030.

- Prefab trucks

Prefab transport movements require heavy-duty trucks. These heavy-duty trucks, that deliver prefab materials, are less urgent to switch to ZE because their transport movements have a large impact on transport movement reduction. After all, materials are not supplied individually by multiple suppliers. The number of transport movements will increase if regulations prohibit the supply of prefab elements and the construction cannot take place with prefab but must be executed on the construction site. Therefore, exemptions should be made for these transport movements if ZE alternatives are inadequate.

- Heavy equipment

The transport movements of heavy equipment are only a small part of the total transport movements during a construction project. One transport movement at the start of the project to deliver the heavy equipment and one transport movement to pick up the heavy equipment when the project stopped making use of it. Furthermore, there is only one logistics solution found that can be applied to heavy equipment which makes it a more difficult transport movement.

- Loader crane truck

A part of the transporter's vehicle fleet has a loader crane and those trucks are more demanded because the loader crane can move the materials at the desired location. The use of the loader crane trucks is therefore more organized to make as much use of loader crane trucks as possible. In general, the load factor is higher than regular trucks.

- Waste

There are several reasons why waste transport is less urgent to switch to ZE. The only feasible logistics solution found for waste is smart returns. However, this only reduces the transport movements and is already done occasionally. The second reason is that the time to pick up waste is more flexible than delivering materials. That allows the transport to take place outside peak hours in the morning and at the end of the afternoon. The third reason is that waste transport has maximum load capacity because it cannot be combined with other flows as it is a return flow. Furthermore, the ZE zones will be a problem for the waste processors as they are mostly responsible for the transport movements of waste and need to adapt their vehicle fleet to be prepared for the ZE zones.

7.3 LOGISTICS SOLUTIONS SCENARIOS

The logistics solutions defined in this chapter need to be put more in practice to show what the list of logistics solutions can do. The logistics solutions do not stand alone and can be combined within a single construction project. There is chosen to give three scenarios applied on a micro, small and medium construction project that use a combination of logistics solutions. The combinations have been determined by combining one or more solutions for personnel transport, tools transport and for material transport because multiple solutions can be used within one construction project. The scenarios will answer the following questions:

- How does the combination work?
- What is the synergy of the combination?

The requirements, costs and benefits of the logistics solutions are described previously and can be found in 7.2.1 Micro renovation projects, 7.2.2 Small renovation projects, 7.2.3 Medium renovation projects and 7.2.5 Costs and benefits logistics solutions. The three scenarios will now be given and afterward a plan of action will be described to put the information into practice where the focus should lie the coming ten years.

7.3.1 LOGISTICS SOLUTION SCENARIO 1

Own ZE vehicle + mobile hub + combine with other sectors, micro project (<150 m^2; <€300,000)

A contractor has bought an own ZE vehicle. This is probably an electric delivery van because electric is the most common for delivery vans to be ZE. However, a hybrid delivery van is also possible. The contractor can use this ZE vehicle to drive to his construction projects with his own tools and can also go to multiple locations during the day. The moment that the contractor orders materials, he will order them for the next day. The materials are in general small in size and light in weight that can be combined well. The order is processed by the supplier which is a wholesaler. This wholesaler analyzes the order and puts the order in an integrated software program that can combine orders of multiple wholesalers. The next morning the mobile hub, operated by a transporter, will drive by all the wholesalers, who have put their orders in the integrated software program, and deliver those orders to the contractors. During the day, the contractor discovers that he misses a specific material and want to have that material delivered the same day. That specific material is something small such as a bag of mortar. An external party that delivers with cargo bikes has a collaboration with the wholesaler. A cargo bike drives by the wholesaler's establishment to pick up the bag of mortar and delivers the bag to the contractor the same day. The cargo bike transporter also has collaborations with other organizations. The transports of those other organizations are combined with the contractor's order. In this way, the contractor does not have to drive back and forth to the wholesaler that will save him time. However, if the wholesaler's establishment is close by, the contractor still has the possibility to pick it up himself because he has an own ZE vehicle.

The synergy is that the personnel and tools transport are being executed together with the ZE vehicle. There are no problems for contractors to reach the construction site with their own tools. The ordered material transport can be combined with the mobile hub and possibly be delivered with a ZE vehicle. In that case, the entire transport is ZE. The synergy of the mobile hub lies in the economies of scale. The more the mobile hub will be used for small orders, the higher the vehicle's load factor will be. Moreover, the mobile hub can be dedicated to deliver in specific neighborhoods which reduces the distance driven within urban area. The same holds for combining with other sectors. The more orders the cargo bike transporter has, the better the orders can be combined to increase the load factor.

7.3.2 LOGISTICS SOLUTIONS SCENARIO 2

Trolley + shuttle bus + CCC, small project (150 – 1,000 m^2; €300,000 - €3 mln)

A contractor has a trolley in which he can store all the tools needed to use during the project. In the morning, the contractor drives to a CCC that is located at the city's edge where he will park his car. A shuttle bus will take that contractor together with other contractors from the CCC to the construction sites where they will be working. If the contractor needs materials, he will order those materials at his supplier that will deliver the materials to the CCC instead of to the construction site. The CCC will

afterward deliver the materials the next morning. At the end of the working day, the shuttle bus will pick up the contractors and bring them back to the CCC where their cars are parked.

The CCC will bundle the contractor's order together with orders either of the same construction project or orders in the neighborhood. This will increase the load factor of the vehicle for last mile transport and decrease the total distance driven in urban areas because transport is dedicated to a neighborhood within the city. The trolley and shuttle bus have excellent synergy because in this way the contractor can bring his own tools within the shuttle bus. Furthermore, the contractor will be transported together with other contractors so that personnel transport movements are decreased. A CCC has high synergy because it combines orders of different suppliers whereas without the use of a CCC, all suppliers deliver their materials separately.

7.3.3 LOGISTICS SOLUTIONS SCENARIO 3

Public transport + locker + building tickets + waiting area for deliveries, medium project (1,000 – 10,000 m^2; €3 mln - €20 mln)

The contractor can either take public transport (train, bus, tram, metro) from home or from the city's edge towards the location. Lockers are provided at the construction site where contractors can store their own tools in lockers. The procurement of the construction project is centralized and performed by the main contractor. The main contractor works with building tickets to communicate to the suppliers when and which materials need to be delivered. The transporter who delivers the supply can sometimes be too early and can wait at a waiting area for deliveries. The moment that the construction site is ready to accept the supply, the transporter will receive a sign of the main contractor where after the transporter will deliver the materials. At the end of the day the contractor will put his tools in his locker and take public transport to go back to his car or home.

The transport of tools is not possible with public transport. Therefore, lockers combine excellent with public transport because the personnel transport and tools transport are disconnected from each other. Waiting area for deliveries mostly go together with building tickets because the supplier/transporter needs to receive a sign that they can come to the construction site. Furthermore, the combination of waiting area for deliveries and building tickets works optimal in medium-sized construction projects because the vehicle's cargo is dedicated to this project and does not have to deliver to other locations.

7.3.4 PLAN OF ACTION 2025 – 2030

The upcoming ZE zones are divided in the first part of the vehicle fleet (passenger cars and delivery vans) for 2025 and the second part for 2030 (trucks). This means that the urgency for the passenger cars and delivery vans is higher than for trucks. Consequently, the focus in the upcoming years must lie on providing logistics solutions for passenger cars and delivery vans. These cars mostly have one objective within the construction logistics, which is personnel transport and additionally tools transport. The contractors must have the ability to reach their destination within the ZE zones with their tools. The found feasible logistics solutions on personnel transport can help them with that challenge. The problem owner is in this case the contractors thus they need to innovate to be prepared for the ZE zones. The next objective is to find logistics solutions for material transport if the personnel

and tools transport are prepared for the ZE zones. The wholesalers and transporters will then become the problem owner (see 5.3 Insights of power-interest matrix and influence-impact matrix).

The plan of action (see Figure 28) can be determined by the stakeholders responsible for the transport combined with the urgency of that transport. A plan of action is to show where the urgency must lie. The upcoming two years are especially important for personnel and tools transport because 2025 is only five years away which is not long considering that freelancers' delivery vans have a depreciation time of 10 years. From 2022 the focus should also start to come to materials transport solutions. This does not imply that material transport solutions should not be started from now until 2022 because the material transport must also be prepared for 2025 and vehicles bought now still might be usable when the ZE zones ban those vehicles. The transitional arrangement states that Euro VI trucks older than five years and Euro VI tractors older than eight years are banned from the ZE zones. That means that a part of the trucks' vehicle fleet is not allowed to enter the ZE zones from 2025 until 2030. The year 2022 is chosen because the personnel and tools transport is the coming years much more important than material transport. Furthermore, electric transport for heavy-duty vehicles is still present on a very small scale (see 4.1.2 Trucks zero-emission transition) and those developments must be known to think about logistics solutions for ZE last mile deliveries.

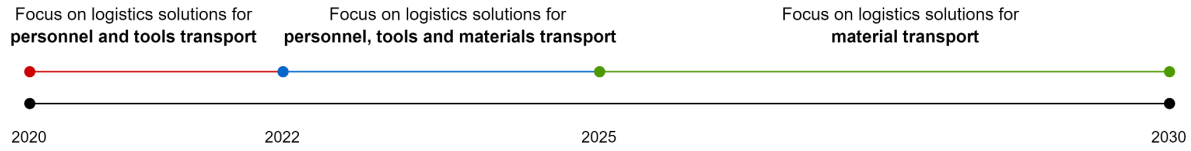


Figure 28: Plan of action for logistics solutions

The plan of action for the stakeholders and what to do with the findings in this report are now discussed to give an advice. Each stakeholder has its own resources and can use them to contribute to sustainable construction logistics. Only the most important stakeholders will be given an advice because they have the most impact.

Main contractors

The most important and urgent thing to do for main contractors is to consider to have a part of their vehicle fleet to be ZE. There is a plan for subsidies of maximum 40% of the additional costs of ZE vehicles (Van Gurp, 2019). This allows them to have the ability to enter the ZE zones from 2025.

Main contractors must assist subcontractors and can do that with several logistics solutions. The collaborations between main contractors and subcontractors must force them to search for solutions together.

Subcontractors

The urgency about applying logistics solutions of subcontractors and their willingness to cooperate with organizing the logistics solutions must increase. The tendency at this moment is that subcontractors will be passive and when it is 2025 they will complain about the ZE zones. Subcontractors must listen and adhere to the demands a main contractor has if a main contractor tries to initiate logistics solutions such as the use of a CCC.

Wholesalers

The wholesalers must stimulate that they will deliver all the materials instead of the contractors picking the materials up. The increase of deliveries must be communicated with transporters to be able to handle the large number of orders. Furthermore, collaborations with transporters can result in innovative solutions such as microhub, mobile hub, minicontainer and combining with other sectors.

Transporters

The transporters must have enough ZE transport to ensure that ZE transport in construction logistics is possible. It is their business model and therefore it must be their trademark to assist the suppliers and contractors with their ZE vehicle fleet.

Municipalities

The municipalities must support innovative logistics solutions with subsidies and must punish traditional fossil fuel construction logistics to make the logistics solutions more competitive and thus attractive. They do not need to set things up themselves but if other stakeholders come up with a plan for a logistics solution the municipalities must cooperate actively to put the logistics solution in motion.

The ZE for heavy-duty trucks is insufficiently present and too expensive. The government must push the vehicle manufacturers to increase the technological developments of heavy-duty trucks. Municipalities can communicate this to the government by addressing the lack of ZE heavy-duty trucks available which makes the ZE zones of 2030 for heavy-duty trucks unachievable.

7.4 CONCLUSIONS ON FEASIBLE LOGISTICS SOLUTIONS

What are feasible logistics solutions to generate transport efficiency and sustainability?

The logistics solutions have been found on the feasible logistics solutions design requirements determined in 3.4 Conclusions on construction projects characteristics, 4.5 Conclusions on current logistics structures and 5.5 Conclusions on objectives and roles of stakeholders. All feasible logistics solutions that generate transport efficiency and sustainability are shown in Figure 24, Figure 25 and Figure 26. These solutions have been applied to renovation projects because these projects are mostly executed by SME contractors. The only additional logistics solution for new construction that has not been determined within micro, small or medium renovation projects is BIM.

However, the focus of this chapter lies on providing a feasible list of logistics solutions for renovation projects. These logistics solutions all contribute to either transport efficiency, sustainability or both. The solutions found for personnel and tools transport can be applied on all sizes of renovation projects with the example of carpooling and shuttle bus for micro renovation projects because the problem in these projects is that the contractors need to go to multiple locations during the day. The solutions for material transport are dependent on whether the project size is micro, small or medium. Especially micro renovation projects have different logistics solutions than the solutions for small and medium.

The goal of ZE has been achieved if logistics solutions have been applied on all types of transport movements (personnel, material, equipment) within a construction project. The semi-structured interviews have led to a list of requirements that is used to find the feasible logistics solutions. However, their perceptions on logistics solutions were useful to recognize their problems with the logistics solutions but also why they prefer or do not prefer the logistics solutions. These perceptions and own

analysis have resulted in requirements, costs and benefits of all feasible logistics solutions. The requirements are necessary to make the solutions feasible. The costs show why others are not willing to adopt a logistics solution and the benefits show on what aspects the solutions have a positive impact.

All logistics solutions require organization time. This can either be before a project or during a project. Logistics solutions differ in the time that they need for their organization. Therefore, the timeline has been constructed to visualize in what phase the relevant stakeholders need to start with organizing. These relevant stakeholders (for each specific logistics solution) will be represented in the booklet so that the stakeholder that uses the product knows which solution applies to that stakeholder, with who he needs to organize the solution and when he must start organizing it. This is also one of the design requirements made earlier in this thesis project (Chapter 5: Stakeholders' objectives and roles).

CHAPTER 8: PRODUCT: INSTRUCTION GUIDE

SQ5: How can the relevant stakeholders be informed about the urgency of the problem and the feasible logistics solutions for small-scale construction projects?

This chapter transforms all the knowledge found during this thesis project into the product to communicate that knowledge to the relevant stakeholders. Firstly, the goal of the product will be explained. Secondly, the design requirements that have been determined during the research and within this chapter, will be given. Thirdly, the evaluation steps that have been taken during the process will be explained. Fourthly, a contractor will be asked for validation on the product's design. Afterward, the product will be shown. Lastly, the conclusions of the product will be discussed. This chapter will answer the fifth and final subquestion.

8.1 GOAL AND SET-UP PRODUCT

This thesis is an academic research and might not be as effective to communicate the results to the representative stakeholders. An easier way to communicate is with a product that is designed in the form of a booklet. These can be designed in a wide variety of options. The goal is that the people relevant to the problem such that their actions have an impact on the problem situation of this thesis project.

Target audience

Contractors are the problem owner so the focus lies on them to understand the instruction guide. However, it is not made for them only. The other stakeholders who are also part of the target audience are wholesalers, transporters and municipalities. This is because the logistics solutions depend on collaborations between stakeholders and because several logistics solutions cannot be executed by contractors. The relevant stakeholders acting in a logistics solution are given for each logistics solution in the instruction guide under the heading 'application'.

8.3 PROCESS DESIGN CYCLE

The process to come to the product's design is performed by the steps in the design cycle (Figure 29). The cycle also has applied to come to the list of feasible logistics solutions (Chapter 7: Feasible logistics solutions) that afterward is used as content for the product.

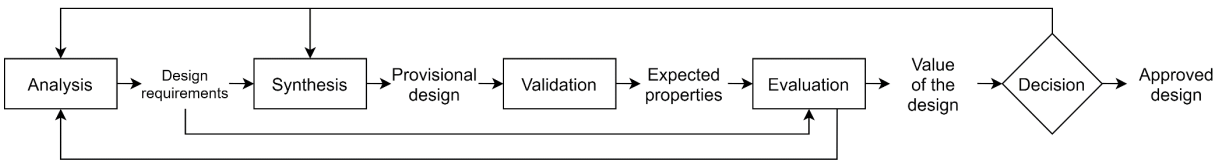


Figure 29: Adjusted basic design cycle based on Roozenburg and Eekels (1995)

Analysis

The functional and non-functional design requirements are the result of the analysis step. These requirements are used to know what needs to be in the guide and how it should be represented. The design principles are an addition to the non-functional requirements in how the product must be designed.

Synthesis

The design requirements have been used to design the first provisional design of the product. Before the first design was made a lay-out had been determined that fits the design principle of familiarity (design principle number 2). This principle has been met by choosing a design where the contractors are familiar with because they are the problem owner until 2025. For that reason, the design of an instruction guide for example to install a kitchen by yourself. The use of steps is not applicable to the logistics solutions. However, the layout and how such an instruction guide is provided has been used as a structure to design the instruction guide in this thesis project. The layout familiarity has been chosen on contractors even though wholesalers, transporters and municipalities are also part of the target audience. The design should be self-explanatory enough that they also understand the product (design principle number 1).

Validation

A contractor, that also has been interviewed in the analysis step, has been asked to discuss the design of the instruction guide. This discussion has led to the validity of the instruction guide's design. The result of this validation is that the contractor was enthusiastic about the guide and thinks that this is a good way to represent the findings. A problem is that contractors are overrun by measures and the coming ZE zones are one of them which will prevent the contractors from making a move. The target audience must gain awareness about the ZE zones and a hard copy of this guide helps to raise that awareness and how to deal with the ZE zones. A digital report will most likely not be read. Therefore, a hard copy summary is more effective than a digital extensive thesis report. This booklet can lay at the coffee table and reach a larger part of the target audience and is therefore an effective way of creating awareness. This validation session shows that the provisional design is suitable.

Evaluation

The comments made by supervisors during the synthesis of the product were used in the evaluation phase. This phase is therefore not the same as it is supposed to be in the design cycle as made by Roozenburg and Eekels (1995) because the comments had mostly been given on the product's content and thus on the design requirements. That is the reason that there is an arrow between design requirements and evaluation and an arrow between evaluation and analysis. The comments that were made in the process of this thesis project are:

- Visualizations with pictures assist in the self-explanatory principle of the design.
- The design must be more demonstrative that the users know what to do with it.
- The overview of logistics solutions requires guidance how to read it.
- The overview of logistics solutions must incorporate colors for solutions that are applicable to multiple circumstances.
- The timeline must be more self-explanatory.

Decision

After each evaluation, there is a decision if the design is finished or not. The last design that has been approved is the final design that is the output of this thesis project. The product will be shown in the

next paragraph (8.4 Instruction guide). The product will also be available as a separate PDF-file to allow the product to be printable.

8.4 INSTRUCTION GUIDE

The instruction guide is a booklet. The format corresponds to an instruction guide. The guide is represented in this next paragraph beginning from the next page. The guide is designed and available in a separate PDF to only print the booklet. Afterward, staples can bind the pages together to make it a booklet.

The set-up of the instruction guide is as follows. Firstly, the guide starts with the necessity of the guide. This start is important to raise a awareness among the users about the problem they are facing. A brief explanation of the ZE zones will contribute to the reader's awareness which is one of the thesis project's objectives. The guide will explain how they can prepare themselves for the ZE zones by offering the list of feasible logistics solutions the moment that they are confronted with that problem. A short description is given on the first page to let the users know what is in the guide. Directly after that explanation why this guide is necessary is the description of small-scale construction projects because this classification has been made within this thesis project but is not known among the product's users.

Secondly, is how to use the product. The product must be self-explanatory. Hence, an explanation of how to use the product must be given directly after the guide's description. Otherwise, the user will be confused and does not know what he should do with it.

Thirdly, is the overview of logistics solutions. This will show all logistics solutions positioned on project size and type of transport movement. At that moment, the users can see if they are already familiar with some of the solutions and if not, what new solutions are there that they want to know more about. Furthermore, this overview is a useful tool to read back during the solutions' explanations for a better understanding.

Fourthly, is the timeline of logistics solutions. The moment that the users think about implementing logistics solutions they should know when they must start organizing the solution. This timeline visualizes that necessity.

Lastly, the logistics solutions will be given grouped on personnel, tools, material and heavy equipment transport. The reason why this sequence is used in this part of the guide is because of the urgency of solutions. Personnel and tools transport has a higher urgency is therefore at the start of this part.

Why this guide?

This guide shows feasible logistics solutions for small scale construction projects in urban areas executed by SMEs, to be prepared for the upcoming zero-emission zones. Please browse through this guide first to see how it is set up.

Zero emission zones
Not yet familiar with the zero-emission zones? The Dutch climate agreement has recently been signed, which indicates that the 30 to 40 largest municipalities will have zero-emission zones. From 2025, it is prohibited to drive into the municipalities with fossil fuel passenger vehicles and fossil fuel delivery vans and from 2030 with fossil fuel heavy vehicles (trucks, tractors). A transitional arrangement has been made in such a way that Euro VI trucks older than 5 years and Euro VI tractors older than 8 years are not allowed to enter the zero-emission zones. The exact areas of the zones still have to be determined.

For who is this guide?
Contractors
Wholesalers
Transporters
Municipalities

It is primarily written for contractors as they will be the first to be confronted with the zero-emission zones but the guide is also written for the other stakeholders necessary for the solutions.

Content
This guide is organized as follows:

- Description of small-scale projects
- How to use the guide
- Overview of logistics solutions
- Timeline logistics solutions
- Logistics solutions:
  - Personnel transport
  - Material transport
  - Tool transport
  - Heavy quipment transport
  - New construction

Zero-emission zones in 30 to 40 largest municipalities

2025

Passenger cars
Delivery vans

Example of a possible zero emission zone. The zones are not yet known.

2030

Box trucks
Trucks
Tractors

Description of small-scale projects

Small-scale projects are grouped into different sizes. This is based on gross floor area and total construction costs. It is an indication so there are no hard limits. The grouping has been applied to renovation construction. New construction is a special case and is less relevant in this guide because it is often carried out by large contractors.

The transport movements are divided into four categories:
- Staff
- Tools
- Material
- Heavy equipment

Micro renovation project

< 150 m²
< €0.3 mln

The project can be seen as a single house renovation / extension. The contractors working on these projects are usually freelancers and sometimes SMEs. Freelancers can have three or four projects in one day. That is why they have to drive to the different locations during the day. Personnel transport in micro projects is a very important aspect and the most challenging to encounter. Furthermore, the tools the personnel bring is also crucial. The contractors need to have their tools at the construction site, otherwise they cannot execute their work. The material transport can be picked up or delivered. The ratio between the two is 50/50%. Heavy equipment is rarely used for micro-renovation projects.

Small renovation project

150 - 1,000 m²
€0.3 - €3 mln

Typical small building renovation projects are residential blocks or low terraced houses. The owners of these buildings are often housing corporations, because they own multiple houses close to each other, that are renovated simultaneously. SME contractors are main contractors in these projects that oursource specific work to freelancers (or smaller SME contractors).

Medium renovation project

1,000 - 10,000 m²
€3 - €20 mln

These projects are still part of small-scale construction projects and are the 'large' small-scale projects. Examples are transformation projects of utility to residential houses. The main contractor is often a larger SME contractor or a small large contractor. There are many transport movements of delivery vans from contractors for personnel and materials supply. These projects contribute significantly to nuisance to the environment of the construction site.

How to use this guide

This page will describe how to use this guide now that you know what the definition of small-scale construction projects are.

The guide's content is focussed on the set of feasible logisitcs solutions to describe what the solutions are, what requirements are necessary to make them feasible and what the costs and benefits are to implement them.

The set of solutions is grouped on personnel, tools, material and heavy equipment. That means that multiple logistics solutions can be combined within one project. The next page will provide three examples of solutions combinations to show what is possible.

To make it more easy to understand how to use the guide, the following steps should be applied.

1. Be aware of the zero-emission zones

You should know about the upcoming zero-emission zones and how it will affect you.

2. Know the definition of small-scale construction projects

You should understand what is meant with micro, small and medium construction projects to know how the solutions have been determined.

3. Stakeholder specific solution

You should read if a logistics solution is applicable to you. This is described at each solution under application.

4. Projects identification

You should identify what projects you normally work in (micro, small or medium) or where you are about to work in to know what logistics solutions might be applicable to you. The overview of logistics solutions is a good tool to use for this step.

5. Collaboration

You should know what stakeholders are necessary to collaborate with.

6. Organization time

You should know in which phase during a construction project you need to start organizing the solution.

7. Implementation

You are now ready to implement one or more logistics solutions.

Combination examples

There is chosen to give three combinations of logistics solutions to show that logistics solutions do not stand alone and even can help each other to create synergy. The combinations are given for a micro construction project (combination 1), a small construction project (combination 2) and a medium construction project (combination 3) and the synergy will be explained.

Combination 1 (micro)
Own zero-emission vehicle + mobile hub + combine with other sectors

The synergy is that the personnel and tools transport is being performed together with a zero-emission vehicle. There are no problems for contractors to reach the construction site with their own tools. The ordered material transport can be combined with the mobile hub and possibly be delivered with a zero-emission vehicle. In that case, the entire transport (personnel, material, tools) is zero-emission. The synergy of the mobile hub lies in the economies of scale. The more the mobile hub will be used for small orders, the higher the vehicle's load factor will be.

Combination 2 (small)
Trolley + shuttle bus + construction consolidation center

The construction consolidation center will bundle the contractor's order together with orders either of the same construction project or orders in the neighborhood. This will increase the load factor of the vehicle for last mile deliveries and decrease the total distance driven in urban areas because transport is dedicated to a neighborhood within the city. The trolley and shuttle bus have a good synergy because in this way the contractor can bring his own tools within the shuttle bus. A construction consolidation center has high synergy because it combines orders of different suppliers.

Combination 3 (medium)
Public transport + locker + building tickets + waiting area for deliveries

The transport of tools is not possible with public transport. Therefore, lockers combine excellent with public transport because the personnel transport and tools transport are disconnected from each other. Waiting area for deliveries mostly go along with building tickets because the stakeholder responsible for delivery needs to receive a sign that they can come to the construction site. Furthermore, the combination of waiting area for deliveries and building tickets works the best in medium-sized projects because the vehicle's cargo is dedicated to this project and does not have to deliver to other locations.

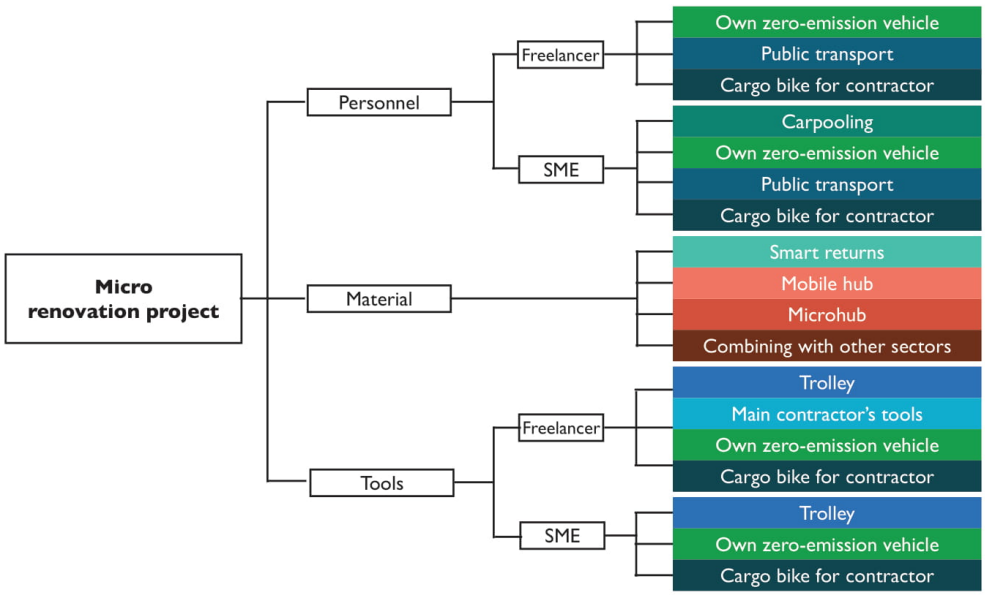
Overview of logistic solutions

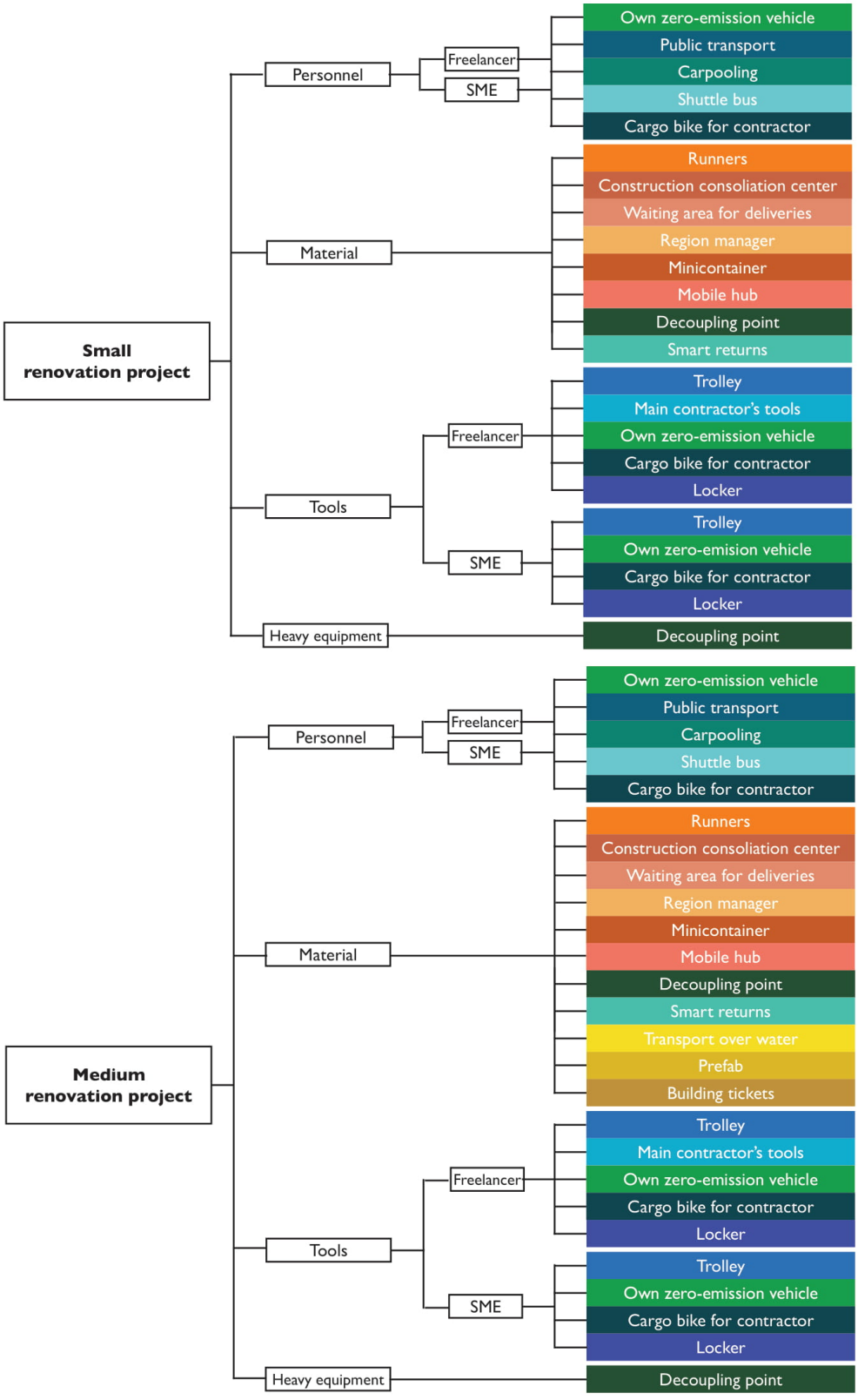
This is a representation of all found feasible logistics solutions grouped on micro, small and medium renovation projects.

Personnel and tools transport are split up into freelancers (who are the subcontractors) and SME (who are the main contractor's personnel).

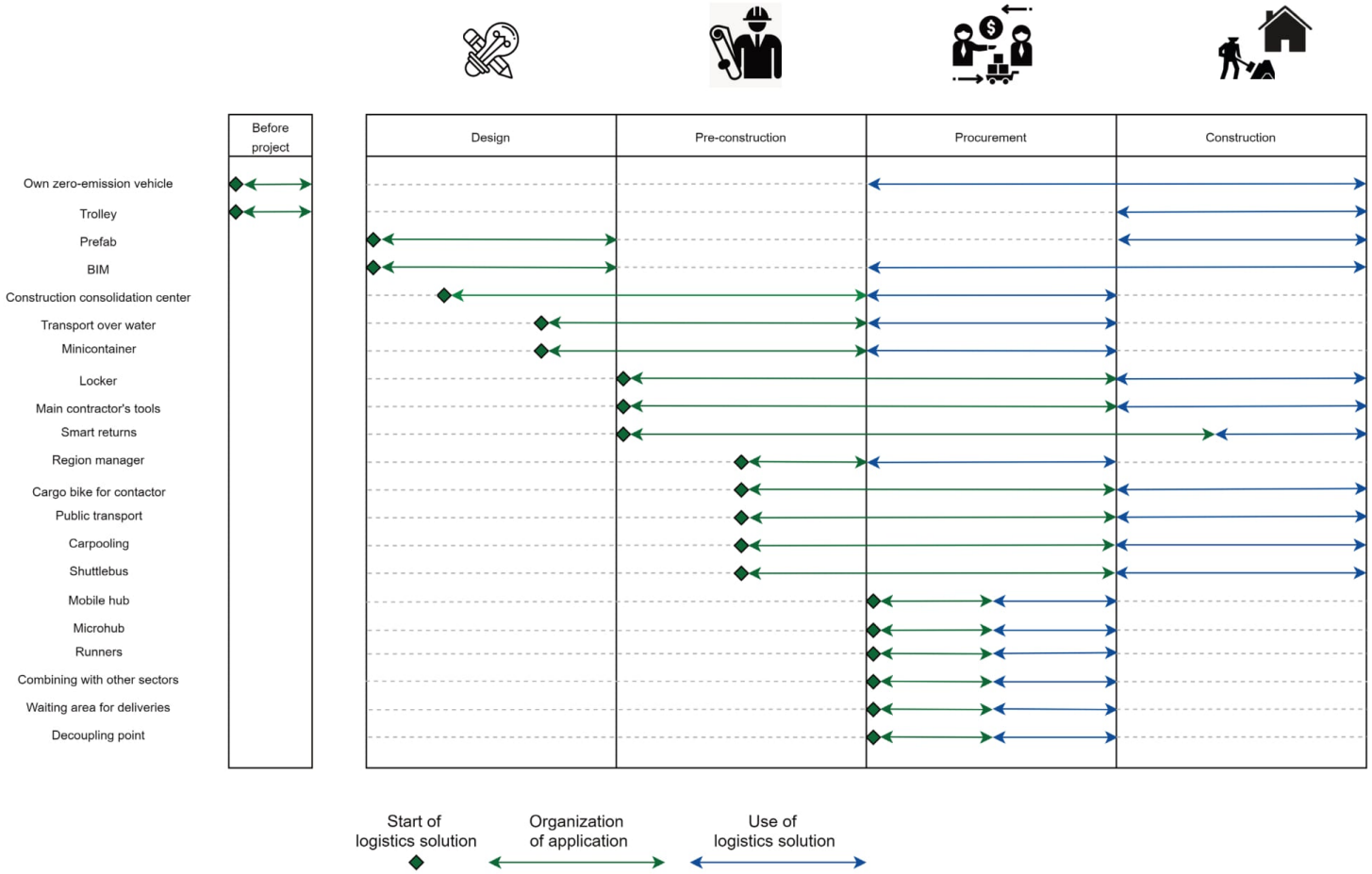
Each logistics solution has an own color in this overview. This is because logistics solutions can be applied in multiple circumstances to visualize these different applications. For example, if an own zero-emission vehicle is used as logistics solution it can be used to transport personnel to the construction site but also their tools. And this zero-emission vehicle can be used for micro, small and medium renovation projects.

This overview is to visualize on which transport movement and on what size of project the solution can be applied. The way it should be read is that you know what project you will be working on (micro, small or medium) and afterwards, you can check what the solutions are, grouped on type of transport movement. At that moment, you know the possible logistics solutions and can check the logistics solutions' details in this guide.




Small renovation project
Personnel
Freelancer
SME
Own zero-emission vehicle
Public transport
Carpooling
Shuttle bus
Cargo bike for contractor
Material
Runners
Construction consolidation center
Waiting area for deliveries
Region manager
Minicontainer
Mobile hub
Decoupling point
Smart returns
Tools
Freelancer
Trolley
Main contractor's tools
Own zero-emission vehicle
Cargo bike for contractor
Locker
SME
Trolley
Own zero-emision vehicle
Cargo bike for contractor
Locker
Heavy equipment
Decoupling point
Medium renovation project
Personnel
Freelancer
SME
Own zero-emission vehicle
Public transport
Carpooling
Shuttle bus
Cargo bike for contractor
Material
Runners
Construction consolidation center
Waiting area for deliveries
Region manager
Minicontainer
Mobile hub
Decoupling point
Smart returns
Transport over water
Prefab
Building tickets
Tools
Freelancer
Trolley
Main contractor's tools
Own zero-emission vehicle
Cargo bike for contractor
Locker
SME
Trolley
Own zero-emission vehicle
Cargo bike for contractor
Locker
Heavy equipment
Decoupling point

Timeline of solutions



Explanation timeline
This timeline shows at what time the organization of the logistics solution must start. That moment is shown with the green diamond in the timeline. Afterwards, the time spent to set up the solution is represented with the green arrow. Finally, the logistics solution will be applied in either the procurement phase, construction phase or both phases with the blue arrow. Two logistics solutions (own zero-emission vehicle and trolley) are already in possession before the project if the solution has been applied. The application of an own zero-emission vehicle is for both procurement and construction because the vehicle can be used to pick up materials (procurement phase) and to use for contractors to drive to the construction site (construction phase).

Note
See in the explanations of the solutions to who the solution applies and which other stakeholders are required for a collaboration.

Design
The design of the project is made. The tendering process starts in this phase and is completed at the end.

Prefab and BIM have to be designed by the architect. Construction consolidation center must be taken into the tendering process and arrangements must be prepared to communicate afterwards to the subcontractors. Transport over water and minicontainer must be communicated with the municipality thus also requires an early start.

Pre-construction
The main contractor has been selected and will assemble his project team and subcontractors at this phase.

Locker, main contractor's tools and smart returns all have to be initiated by the main contractor and this must start at the beginning of pre-construction. Region manager requires less organization time and must be done halfway during pre-construction. Cargo bike for contractor, public transport, carpooling and shuttlebus are all personnel transport solutions and must be performed during the assembly of the project team.

Procurement
The materials are purchased during this phase.

The blue arrows starting in the procurement phase are solutions that apply on the supply of materials. Mobile hub, microhub, runners, combining with other sectors, waiting area for deliveries and decoupling point must be started organizing from this phase because that can only be organized if the materials are ordered at the suppliers.

Construction
The project is being executed.

The blue arrows in the the construction phase are mostly present there because these are applications of personnel and tools transport solutions: own zero-emission vehicle, trolley, locker, main contractor's tools, cargo bike for contractor, public transport, carpooling and shuttle bus. Prefab and BIM change the way of construction. Smart return is the return flow of waste.

Personnel transport

Logistics solutions

Own zero-emission vehicle (personnel)

Application

- Micro, small, medium
- Contractor, municipality

A private electric vehicle gives freelancers the freedom to move wherever and whenever they want in urban areas after the zero-emission zones have been initiated. Freelancers can have several projects a day at different locations, making this the best possible logistics solution for personnel transport in micro projects. Moreover, if the freelancer has many tools that he all needs during a day, he will want his own vehicle.

The SME contractor has its own vehicle fleet. This fleet consists out of several vans of different ages. A complete zero-emission fleet is not necessary. Part of the fleet is sufficient.

Requirements

- Financial support to purchase the zero-emission vehicle.
- Charging infrastructure throughout the country needs to assist that charging while at work is possible.
- High density of charging stations in urban areas.
- Loading infrastructure at the contractor's establishment to charge the vehicles outside working time. (SME personnel)
- Planning of zero-emission vehicle use. (SME personnel)

Costs

- High purchase price
- Limited range
- Depending on charging infrastructure

Benefits

- Ability to enter zero-emission area
- No emissions
- Flexible to travel between projects
- Less material planning required
- Less maintenance costs
- Storage space for tools

Public transport

Application

- Micro, small, medium
- Contractor, municipality

Freelancers SME contractors' personnel can go from home or from the city's edge to the location by public transport.

Requirements

- Good public transport connections within the zero-emission zone.
- Locations at the city's edge must be organized in a way that they can park their vehicle and walk to the public transport.
- The necessary tools need to be provided on the location or the freelancer needs to carry it with him.
- Behavioral change of contractors.
- Material transport must all be delivered by wholesaler/ transporter.
- Contractors must plan their work and procurement.
- Public transport travel time between projects must not exceed own vehicle travel time significantly.

Costs

- Extra travel time
- Walk to projects
- Inflexible to travel between projects
- Inflexible to buy materials
- Limited number of own tools

Benefits

- Ability to enter zero-emission zones
- Lower emissions
- No parking costs
- No additional transport movements

Personnel transport

Logistics solutions

Carpooling

Application

• Micro, small, medium
• Freelancer (not for micro because then they have several projects), SME contractor, transporter

SME contractor personnel are colleagues and can share the use of their vehicle by carpooling. The vehicle's occupancy rate increases, resulting in fewer transport movements. Carpooling is impossible for freelancers in micro projects because they can have multiple jobs in one day.

Requirements

• Planning of work performed at one single location needs to be adjusted in order that all personnel driving together at the project have enough tasks to perform during the day.
• The delivery van needs to be zero-emission from 2025.
• Personnel needs to live close enough to each other or live on the way to the location.

Costs

• Extra travel time
• Inflexible to travel between projects
• Inflexible to buy materials
• Difficult during epidemics

Benefits

• Ability to enter zero-emission zones (if the vehicle is zero-emission)
• No emissions (if the vehicle is zero-emission)
• Shared use of zero-emission (if vehicle is zero-emission)
• Fewer transport movements
• Shared parking costs
• Shared transport costs

Cargo bike for contractor

Application

• Micro, small, medium
• Contractor, transporter

With a cargo bike (can be electric) you can cycle from the city's edge to the construction site. The contractor's vehicle can be parked at the bicycle location. It is also possible to take an ordinary electric bike in case the tools and materials are on the construction site.

Requirements

• Organization of the cargo bike's business model.
• Behavioral change that contractors take a bicycle.
• Tools and materials must fit in the cargo bike if the tools and materials have to be carried.

Costs

• Limited number of own tools
• Unattractive in bad weather

Benefits

• Zero-emission transport
• No parking costs
• Flexible to travel between projects

Personnel transport

Logistics solutions

Shuttle bus

Application
- Small, medium
- Contractor, transporter

A shuttle bus (possibly electric) drives from the city's edge to the construction sites. The more people who use a shuttle bus service, the less time it will take to arrive at the destination because the shuttle buses can be grouped by neighborhoods.

Requirements
- Location at the city's edge to park the contractors' vehicles. Can be a parking lot (P+R) or a wholesaler's establishment.
- Organization of the shuttle bus.
- Main contractor must communicate that this is an option for the freelancer subcontractors and how they can make use of it.
- Contractor must move his tools easily from own vehicle to the shuttle bus.
- Tools need to fit in the shuttle bus.

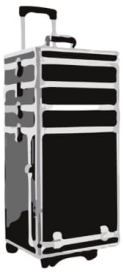
Costs
- Inflexible to travel between projects
- Inflexible to buy materials
- Limited number of own tools

Benefits
- Ability to enter zero-emission zones (if the vehicle is zero-emission)
- No emissions (if the vehicle is zero-emission)
- Shared use of zero-emission (if vehicle is zero-emission)
- Fewer transport movements
- No parking costs

Tools transport

Logistics solutions

Trolley



Application
- Micro, small, medium size
- Contractor

A trolley can be used to store all the necessary tools. The contractor is not limited to use his own delivery van to bring his tools.

The tools needed for SME contractors' personnel is even less because the personnel can combine their tools.

Requirements
- Trolley must be able to store all the necessary tools.
- Contractor must think better about which tools are needed in a day.
- Behavioral change of contractors.

Costs
- Limited space

Benefits
- Not dependent on own delivery van
- Flexibility to move to different locations

Main contractor's tools

Application
- Micro, small, medium
- Contractor

The main contractor provides his tools to his subcontractors. Freelancers are more flexible if they only have to bring their own small tools. Large tools such as a circular saw table must be available on site.

Requirements
- Main contractor willing to share his tools.
- Trust between main contractor and the freelancers.

Costs
- Extra costs for main contractor
- Possible theft

Benefits
- Subcontractors not dependent on own tools
- Possibility to share personnel transport
- Shared use of tools

Tools transport

Logistics solutions

Own zero-emission vehicle (tools)

Application
- Micro, small, medium size
- Contractor, municipality

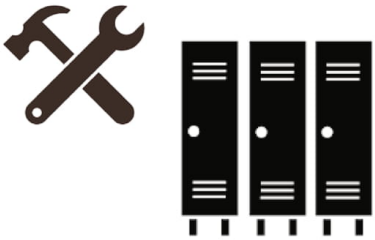
Tools transport is possible without problems if a contractor owns a zero-emission vehicle.

Requirements
- Financial support to purchase the zero-emission vehicle.
- High density of charging stations in urban areas.
- Loading infrastructure at the contractor's establishment to charge the vehicles outside working time. (SME personnel)
- Planning of zero-emission vehicle use. (SME personnel)

Costs
- High purchase price
- Limited range
- Depending on charging infrastructure

Benefits
- Ability to enter zero-emission zones
- No emissions
- Flexible to travel between projects
- Less material planning required
- Less maintenance costs
- Storage space for tools

Locker



Application
- Small, medium
- Contractor

The necessary tools can be stored and locked at the construction site.

Requirements
- Main contractor's personnel and subcontractors must not have multiple projects during one day.
- Main contractor must provide and manage the lockers.

Costs
- Inflexible to work on multiple projects
- Storage area on construction site

Benefits
- No transport of tools
- No theft

Tools transport

Logistics solutions

Cargo bike for contractor

Application
- Micro, small, medium
- Contractor

With a cargo bike (can be electric) you can cycle from the city's edge to the construction site. The contractor's vehicle can be parked at the bicycle location. It is also possible to take an ordinary electric bike in case the tools and materials are on the construction site

Requirements
- Organization of the business model of the cargo bike.
- Behavioral change that contractors take a bicycle.
- Tools and materials must fit in the cargo bike if the tools and materials are to be carried.

Costs
- Limited number of own tools
- Unattractive in bad weather

Benefits
- Zero-emission transport
- No parking costs
- Flexible to travel between projects

Material transport

Logistics solutions

Microhub

Application

- Micro
- Wholesaler, transporter, municipality, contractor

A microhub is a location with space for completion construction materials and not for large heavy materials. This hub acts as a decoupling point between construction sites and suppliers. The last mile can then be transported zero-emission by electric vehicles or a cargo bike or contractors can pick it up themselves.

Requirements

- Contractors must plan their work and procurement.
- Organization of the microhub.
- Tactical location for an establishment.
- Order handling IT system needs to know when an order can make use of the microhub in terms of volume, length sizes and stackability of the orders' products.
- Universal materials data usage.
- Material transport must all be delivered by a wholesaler/transporter.
- High use of the microhub to increase load factor.

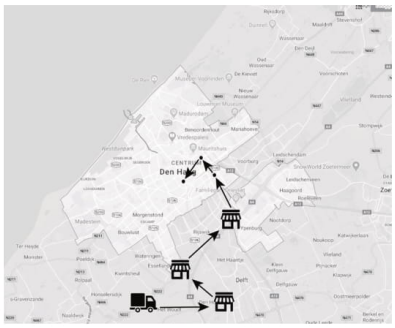
Costs

- Storage costs
- Last mile delivery costs
- No delivery by supplier's driver

Benefits

- Fewer transport movements
- Shared use of zero-emission (if last mile vehicle is zero-emission)
- Ability to deliver overnight
- Freedom of choice for supplier

Mobile hub



Application

- Micro, small, medium
- Wholesaler, transporter

A mobile hub is a large vehicle that picks up from various suppliers and supplies to multiple construction projects.

Requirements

- Contractors must plan their work and procurement.
- The organization of the mobile hub.
- Order handling IT system needs to know when an order can make use of the mobile hub in terms of volume, length sizes and stackability of the orders' products.
- Universal materials data usage.
- Material transport must all be delivered by wholesaler/ transporter.

Costs

- Last mile delivery costs
- No delivery by supplier's driver

Benefits

- Fewer transport movements
- Shared use of zero-emission (if last mile vehicle is zero-emission)
- No competitor's logo on vehicle

Material transport

Logistics solutions

Combining with other sectors

Application

- Micro
- Wholesaler, transporter

Small materials that are ordered can be delivered quickly when it is combined with other sectors. Last mile can be performed with cargo bikes or electric vehicles.

Requirements

- Materials need to fit in the vehicle.
- Order handling IT system needs to know when an order can make use of shared vehicle in terms of volume, length sizes and stackability of the orders' products.
- Universal materials data usage.

Costs

- Only small materials

Benefits

- Fewer transport movements
- Ability to make rush trips
- Shared use of zero-emission (if vehicle is zero-emission)

Smart returns

Application

- Micro, small, medium
- Wholesaler, transporter

The loader crane truck can be used directly after the supply of materials to take back waste or incorrectly delivered materials.

Requirements

- Communication and collaboration between the waste transporter and contractors. The contractor needs to share that they have full big bags or waste containers that can be taken away.
- The vehicle used for supply needs to be able to transport the full waste container.

Costs

- Operational costs

Benefits

- Fewer transport movements
- Less waste on the construction site
- Lower costs for road block permits
- More storage space on construction site

Material transport

Logistics solutions

Runners

Application

- Small, medium
- Wholesaler, transporter, contractor

Runners can move the materials to the exact location where they are needed. The person responsible for transport or the contractor himself can do this. Contractors do not longer have to search for and carry the materials themselves and can work directly with the materials when they arrive at the location.

Requirements

- Main contractor has to indicate what materials are needed at which location on the construction site.
- Contractors must plan their work and procurement.

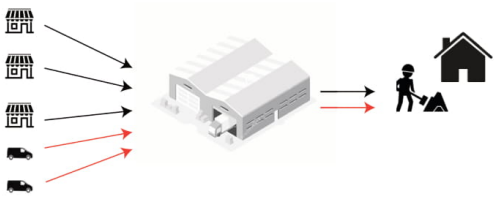
Costs

- Labor costs

Benefits

- Increased work efficiency of personnel
- Lower hourly rates for runners than for contractors
- Possibility for delivery outside construction time

Construction consolidation center



Application

- Small, medium
- Wholesaler, transporter, contractor, municipality

All material transport uses the construction consolidation center to store the material at the city's edge. Afterwards, the materials will be bundled and delivered to the construction sites. An additional service can be a place for contractors to park their car and be transported from the construction consolidation center to the construction site.

Requirements

- Procurement must be performed centralized.
- Contractors must plan their work and procurement.

Costs

- Storage costs
- Operational costs

Benefits

- Fewer transport movements
- No emissions (if last mile vehicle is zero-emission)
- Shared use of zero-emission (if last mile vehicle is zero-emission)
- Just-in-time deliveries

Material transport

Logistics solutions

Waiting area for deliveries

Application
- Small, medium
- Main contractor, transporter

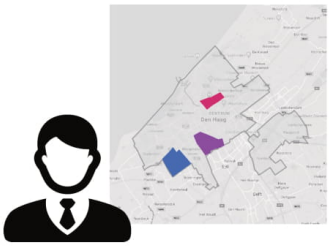
Trucks are waiting on the city's edge and wait for a sign to deliver the materials. This logistics solution is advantageous if limited storage space is available on site.

Requirements
- Available location on city's edge close to the construction site where vehicle can be parked for free.
- Planning by main contractor.
- The driver is willing to wait.
- Truck is dedicated for the construction project and not for other projects. Otherwise, conflicts will arise to deliver other projects.

Costs
- Waiting costs

Benefits
- Just-in-time deliveries
- Less traffic jams
- Less nuisance

Region manager



Application
- Small, medium
- Main contractor, municipality, wholesaler

An independent person who knows the projects in a city and who can manage the coordination between the projects. The supply of materials can be synchronized and delivered together in a neighborhood.

Requirements
- Contractors must plan their work and procurement.
- Organization of the region manager.
- Contractors need to share information about their orders.
- Different suppliers need to be bundled together.
- Order handling IT system needs to know when an order can make use of the mobile hub in terms of volume, length sizes and stackability of the orders' products.
- Universal materials data usage.
- Material transport must all be delivered by wholesaler/ transporter.

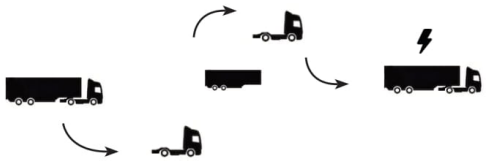
Costs
- Labor costs
- Inflexible delivery period

Benefits
- Fewer transport movements

Material transport

Logistics solutions

Decoupling point



Application

- Small, medium
- Transporter

Materials are delivered on the city's edge and loaded directly with outgoing materials without intermediate storage. Trailers can be disconnected from tractors and the last mile can be driven with a zero-emission tractor. Construction consolidation centers can offer this as a service to transport last mile zero-emission.

Requirements

- Decoupling point needs to have zero-emission trucks and tractors.
- IT logistics system needed at decoupling point.
- Charging infrastructure available at decoupling locations.
- Technologically feasible to decouple and couple trailer.

Costs

- Operational costs
- Extra last mile delivery costs
- Extra travel time
- No own driver for delivery

Benefits

- Zero-emission transport
- No storage costs
- Ability to coordinate Just-In-Time deliveries

Minicontainer

Application

- Small, medium
- Wholesaler, transporter, contractor, municipality

A small container dedicated to a construction project. Projects have temporary housing and waste containers, usually in parking lots and this minicontainer can be added to this set of temporary housing. Tools can also be stored in the minicontainer.

Requirements

- Materials must fit in the container.
- Enough space available in public space to place the container.
- The supplier and the contractor need to have a key to open the container.
- The municipality must give a permit.

Costs

- Costs for the public space area

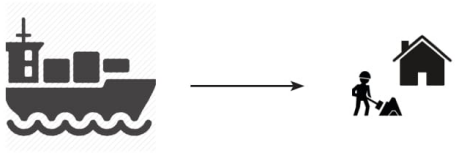
Benefits

- Fewer transport movements
- Ability to deliver overnight

Material transport

Logistics solutions

Transport over water



Application

- Medium
- Wholesaler, transporter, municipality

A change in modality from road to water. The last mile in urban areas can be transported by water. A common practice is that water transport is combined with a construction consolidation center for optimal loading capacity of last mile deliveries.

Requirements

- Construction site must be close to water.
- Additional actions are needed to hoist the materials from the boat to the building.
- Boats must be allowed to dock close to the location.

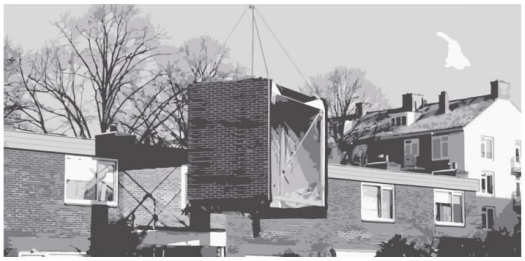
Costs

- Action to transport materials from water to land
- Only possible for construction sites near water
- Extra last mile delivery costs

Benefits

- No material transport movements by road
- Extra storage space
- No sagging quays
- More material stock per movement

Prefab



Application

- Medium
- Transporter, producer

A part of the construction project is prefabricated before going to the construction site. Medium-sized renovation projects are large enough that prefab can be a feasible solution.

Requirements

- Producer must be capable of producing the materials prefab.
- The materials must fit in a truck or on a trailer.
- The materials need to be able to be placed at the right location on the construction site.

Costs

- No customer specifications
- Extra costs for special transport

Benefits

- Fewer transport movements
- Shorter construction time on site
- High quality control
- Less construction time on construction site

Material transport

Logistics solutions

Buildingtickets

Application
- Medium
- Transporter, main contractor, producer

The supplier is given a signal from the main contractor at what time and which materials are needed in the main contractor's planning. This works in combination with a construction consolidation center or waiting area for deliveries.

Requirements
- Contractors must plan their work and procurement.
- Communication between the main contractor and supplier that an approval is given when the supplier may deliver the materials.
- Truck is dedicated for the construction project and not for other projects. Otherwise, conflicts will arise to deliver other projects.

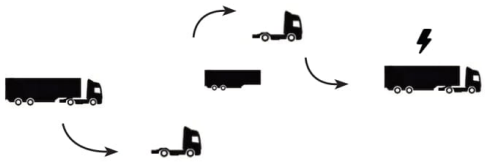
Costs
- Administrative effort
- Wrong information on ticket in case of delay
- Not always adhered to

Benefits
- Just-in-time deliveries
- Less traffic jams

Heavy equipment transport

Logistics solutions

Decoupling point



Application
- Small, medium
- Transporter

Heavy equipment is often placed on a trailer. A decoupling point allows the last mile to be zero-emission.

Requirements
- Heavy equipment can fit on a trailer.
- Decoupling point needs to have zero-emission trucks and tractors available.
- IT logistics system needed. The decoupling point's organizer needs to incorporate this in their operations.
- Charging infrastructure available at decoupling locations.
- Technologically feasible to decouple and couple trailer.

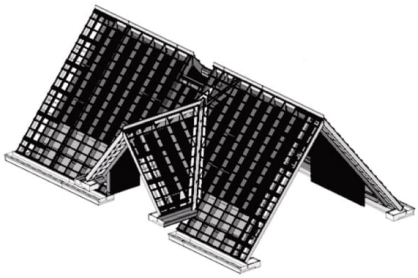
Costs
- Operational costs
- Extra last mile delivery costs
- Extra travel time
- No own driver for delivery

Benefits
- Zero-emission transport
- No storage costs
- Ability to coordinate just-in-time deliveries

New construction

Logistics solutions

BIM



Application

- Small, medium (new construction)
- Main ontractor, architect, suppliers

All solutions applied on medium renovation projects can also be applied on new construction. BIM is the only solution for new construction

The work to be performed has been digitized in a 3D model and the materials required are in this model. The construction work can be combined with the planned materials required. In this way, the material flow can be coordinated to have a just-in-time offer. In addition, the materials can be bundled better because the entire process is placed in the model.

Requirements

- Architect must be familiar with BIM.
- Logistics coordinator to communicate the material output of BIM with the suppliers.

Costs

- High architect costs
- Additional design time

Benefits

- Precise material requirement
- Improved just-in-time deliveries
- Less lead time at construction site
- Less construction mistakes

Research

The results of the research that led to this guide were conducted through interviews with stakeholders in the construction logistics chain. Questions were asked what the current logistics structures are for small-scale construction projects, how the relevant stakeholder operates and how they look at logistics solutions. The logistics solutions that were asked were based on previously conducted research on large-scale projects, carried out by TNO.

Sources pictures

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8.5 CONCLUSIONS ON INSTRUCTION GUIDE

This paragraph will evaluate the instruction guide and answer the last subquestion. The instruction guide is verified on the determined design requirements. The verification is represented in Table 18 below.

Table 18: Verification of the booklet's design requirements

Requirement	Type of requirement	Verification
The product must make the stakeholders aware about the upcoming ZE zones.	Functional requirement	The first page describes and visualizes the ZE zones.
The product must contribute to less transport movements made by the construction sector.	Functional requirement	The logistics solutions have fewer transport movements as benefit.
The product must contribute to less emissions made by the construction sector.	Functional requirement	The logistics solutions have ZE transport as benefit and fewer transport movements also leads to less emissions.
The product must provide a list of feasible logistics solutions that can be applied in small-scale construction projects.	Functional requirement	The logistics solutions have been determined on small-scale construction projects and that definition is explained.
The product must support collaborations between stakeholders.	Functional requirement	The involved stakeholder for each logistics solution is given.
The product must focus on projects executed by SMEs.	Non-functional requirement	The logistics solutions are focused on small-scale construction projects.
The product must focus on the 30-40 municipalities in the Netherlands where the ZE zones will be established.	Non-functional requirement	The research is conducted within Dutch interview respondents and the Dutch ZE zones regulations are explained.
The product must separate logistics solutions on micro, small and medium sized construction projects.	Non-functional requirement	Each logistics solution has information on which construction project size it can be applied.
The product must focus separate renovation projects and new construction.	Non-functional requirement	The logistics solutions are dedicated to renovation projects and also explain which solutions can be applied on new construction projects.
The product must focus mostly on renovation projects.	Non-functional requirement	Almost all logistics solutions (except BIM) are applicable on renovation projects and in the description of small-scale projects it is described that new construction is less relevant.
The product must address the urgency of the problem.	Non-functional requirement	The first page (*Why this guide?*) addresses the urgency of the problem.
The product must categorize logistics solutions on personnel, material, tools and heavy equipment.	Non-functional requirement	The logistics solutions are categorized on personnel, material, tools and heavy equipment. These categories are the header of each page of the logistics solutions.
The product's target audience are the key players and the context setters: contractors, transporters, suppliers and municipalities.	Non-functional requirement	The target audience is explained in the first page.
The product must indicate which stakeholders are part of a logistics solution so that they know they know who to cooperate with.	Non-functional requirement	The stakeholders required for each solution are given.
The product must be self-explanatory.	Design principle	An explanation on how to use the guide is given.
The product must be understandable by the user with a design that they are familiar with.	Design principle	The design's lay-out is based on an instruction guide of how to build something such as a kitchen.
The product must limit the options to what the user need.	Design principle	The product is a summary of this thesis project with all necessary information given.
The product must chunk down the information into logical groups.	Design principle	The logistics solutions are given on personnel, tools, material and heavy equipment.
The product must not go into too much detail.	Design principle	A short explanation of each solution is given.
The product must not have abbreviations.	Design principle	The only abbreviations are the ones that the users know the abbreviation better than the entire phrase. These are SME, BIM and IT.
The product must be printable.	Design principle	The design is made on A4 landscape that allows the product to be printable by any printer and only staples are needed to make it a booklet.

How can the relevant stakeholders be informed about the urgency of the problem and the feasible logistics solutions for small-scale construction projects?

To conclude this chapter the fifth and last subquestion is answered by that the relevant stakeholders can be informed with the developed product: the instruction guide. The determined design requirements have been used to know what needs to be communicated to inform the relevant stakeholder and in what way this communication must be performed. The design cycle has been used to design the product in order to maximize the product's intended use and that is to inform the stakeholders about the urgency of the problem and the feasible logistics solutions. The evaluation of the predetermined design requirements leads to the conclusion that the final product has met those requirements.

CHAPTER 9: CONCLUSIONS, DISCUSSION AND RECOMMENDATIONS

9.1 CONCLUSIONS

A list of five subquestions was constructed to find the answer to the main research question. The purpose of the first three subquestions was a descriptive research to understand the phenomena occurring presently and to discover the problems in small-scale construction projects' logistics. A deductive research approach was applied to the last two subquestions and was focused to answer the main research question. The main research question is: "*Which logistics solutions fit the requirements of small-scale construction projects in urban areas with the purpose of minimizing transport movements and emissions, that can be adopted by the relevant stakeholders?"*. So far, no research had been performed that analyzed small-scale construction projects. Only research on larger projects had been performed.

The research started with literature review on previously found logistics solutions. This developed a list of logistics solutions found in Appendix II. These solutions are analyzed and proven to have a positive impact on reducing transport movements and emissions in construction logistics. Afterward, semi-constructed interviews have been held. A total of fifteen respondents have been interviewed. These respondents represent the different stakeholders (contractors, wholesalers, transporters, municipality) active in the construction logistics and who are key players regarding the problem situation. The interviews resulted in qualitative data on their perspectives on current problems and possible logistics solutions.

The first subquestion "*What are the characteristics of small and medium sized projects executed by SMEs?"* was necessary to understand the definition of small-scale construction projects. The characteristics led to a division into micro (<150 m^2; <€300,000), small (150 – 1,000 m^2; €300,000 - €3 mln) and medium sized (1,000 – 10,000 m^2; €3 mln - €20 mln) construction projects. SMEs are generally more into renovation construction projects especially in urban areas because the houses are already build. New construction projects are executed occasionally by SMEs. Therefore, these are less relevant to the projects executed by SMEs thus less important. Furthermore, construction projects always operate with a main contractor and subcontractors in which subcontractors mostly are freelancers or micro enterprises. These subcontractors are the main executors of the work of small-scale construction projects and feasible logistics solutions must be found for these subcontractors.

The second subquestion "*What are the current logistics structures for small-scale construction projects?"* started with a vehicle classification. It must be known what vehicles are used for what purposes to understand construction logistics. Afterward, literature was found that describes the small-scale construction logistics. Only a few anonymized pilot projects of medium size were available to analyze in detail what transport movements are present during an entire project. Delivery vans are found to contribute the most to the number of transport movements in urban areas out of all construction logistics. Subcontractors and sometimes personnel of main contractors tend to pick up materials themselves at the wholesaler. However, if the wholesaler's establishment is too far away they choose to have the materials delivered. Thus, contractors can plan if necessary.

A stakeholder analysis has been applied to answer the third subquestion "*How do the objectives and roles of the various stakeholders involved affect the transport movements in construction logistics?"*. The stakeholders' resources gave insight into their position in the construction logistics supply chain. The main problem found is that subcontractors have too low interest and influence to adopt new logistics solutions. Other stakeholders are willing to help if it is possible. That means that the costs should not weigh more than the benefits. The main contractor is found to be the most important key player. However, they cannot achieve all logistics solutions without the help of wholesalers, transporters and municipalities. This insight results in the target audience of the final product that has a focus on contractors but is also for wholesalers, transporters and municipalities.

The fourth subquestion "*What are feasible logistics solutions to generate transport efficiency and sustainability?"* uses the results of the first three subquestions. In general, logistics solutions are not applied by stakeholders because the costs outweigh the benefits. The contractors' change of culture is crucial to make logistics solutions feasible. A list of feasible logistics solutions is provided in 7.2 Feasible allocation of logistics solutions. Requirements have been determined which indicate what is necessary to make logistics solutions feasible. The solutions have different impacts and can either generate transport efficiency, sustainability or both. These impacts are given in the costs and benefits of the solutions.

The fifth and final subquestion "*How can the relevant stakeholders be informed about the urgency of the problem and the feasible logistics solutions for small-scale construction projects?"* has the goal to summarize the findings of this thesis project in a way that it is easily accessible and understandable for the relevant stakeholders. A booklet has been designed that can be published and printed separately. The first three subquestions were the analysis step of the design cycle where the fourth and fifth subquestions were the synthesis of the design requirements. Those design requirements resulted in a product that is the answer to this fifth subquestion. The product will communicate the urgency of the problem and feasible logistics solutions to the relevant stakeholders.

To conclude, the costs and benefits need to be known for the stakeholders. Future research should analyze the impacts of the proposed feasible logistics solutions to quantify the costs and benefits. The stakeholder analysis and semi-constructed interviews resulted in that the stakeholders are still too passive and nobody knows who should take the lead. The upcoming ZE zones will make an impact and initiate a move that makes the traditional construction sector less traditional. Regulations from higher up are not always appreciated but will be adhered to if feasible. This thesis project shows where the opportunities lie to reduce the emissions in urban areas caused by small-scale construction projects' logistics.

Which logistics solutions fit the requirements of small-scale construction projects in urban areas with the purpose of minimizing transport movements and emissions, that can be adopted by the relevant stakeholders?

The first part of the main research question (*Which logistics solutions fit the requirements of small-scale construction projects in urban areas*) have been found in Chapter 7: Feasible logistics solutions. This does not mean that the solutions found are all the solutions possible thus opportunities to set up new innovative solutions are still possible. However, based on a literature review and problem analysis this found list of solutions does cover the most important logistics in small-scale construction projects, which are the contractors' delivery vans and material supply transport movements. The second part of the main research question (*with the purpose of minimizing transport movements and emissions*) is answered by the benefits of the logistics solutions (Table 17). The found logistics solutions have an impact on different factors which can either be minimizing transport movements or emissions but also other factors that support synergy that results in fewer transport movements and/or emissions.

Transport movements of concrete, prefab, heavy equipment, loader crane trucks and waste are less urgent or more difficult to find feasible logistics solutions to. Therefore, developments in ZE transport need to be monitored by municipalities to determine if the ZE zones are achievable for these transport movements. The third and final part of the main research question (*that can be adopted by the relevant stakeholders*) is answered by the development of the final product. The solutions are communicated in this way to the relevant stakeholders (contractors, wholesalers, transporters, municipalities) such that they know which solutions can be adopted by them.

It is concluded that the most important requirement within the construction sector is that contractors need to improve their planning. The further away the wholesaler's establishment is from the construction site, the more the contractors had the materials delivered. This led to the conclusion that contractors can plan if it is necessary. The contractor who validated the instruction guide (see 8.3 Process design cycle) confirmed that subcontractors can plan when the need is present. The planning of contractors is crucial because it is a requirement of most found feasible logistics solutions. Contractors in small-scale construction projects are used to pick-up their materials in the morning or during the day if they forget something.

Lastly, the transportation of completion construction materials is feasible to deliver ZE whereas the transportation of shell construction is much more difficult. The specialists in the field of logistics are the transporters. The transporters need to be prepared for the ZE zones because organizing transport is their revenue model. Contractors and wholesalers are less concerned about logistics because it is not their key activity. This shows that transporters will provide circumstances that the material supply can be performed ZE and opportunities will come to the transporters to differentiate themselves with wholesalers and contractors because they might not be prepared for the ZE zones.

9.2 DISCUSSION

This thesis project is an initial effort to analyze the small-scale construction projects in terms of its logistics and where opportunities lie to decrease the transport movements and emissions within urban areas. The main challenge during this thesis project was the gathering of quantitative data. The research method applied was semi-constructed interviews which only resulted in qualitative data. Expected was that there was more data present among the respondents that could assist in calculations for impacts of scenarios. However, contractors do not have such data because small-scale construction projects' contractors do not have the capacity to collect and analyze the data. The thesis project has been reshaped to focus on the problem analysis and previously found logistics solutions in literature because of this lack of data. Large contractors do have innovative departments focused on these kinds of subjects and previously found logistics solutions have been found with the help of those large contractors. The data that could have helped for the impacts of scenarios for small-scale construction projects are mentioned in 9.3 Recommendations. Another reason why the data is unavailable is that main contractors do not have information about their subcontractors. The main contractors hire subcontractors for a task. The subcontractors purchase their materials individually which makes the material supply fragmented over many suppliers.

The conducted interviews have led to findings of small-scale construction projects' logistics. These findings have not been generated before and give a new understanding of how the logistics structures are set up and which logistics solutions can be applied to those structures. However, interviews cannot be used to know everything. The main characteristics and problems within the logistics are asked in the interviews where the respondents only give selective information. The respondents will not

describe in detail what the logistics are. Therefore, assumptions had to be made to the interviews' results to apply on micro, small and medium size projects. Furthermore, there is no data about vehicles used in small-scale construction projects. Assumptions were made based on heavy traffic that drives on the Dutch highways.

One interview respondent was willing to share a dataset of eight customers' orders. The dataset is limited but gave interesting insights into their pick-up/delivery behavior. The certainty about the conclusions regarding when they pick up the materials or that the materials are delivered would be higher if the dataset included more customers. Furthermore, the dataset did not include the time when they pick up their materials. Therefore, it is unknown whether the pick-up was a rush order or a morning pick-up.

The lack of data contributes to the fact that stakeholders are unwilling to adopt new logistics solutions. They do not know the exact contribution of logistics costs of the total costs. The research is based on the interviews' qualitative data and literature. However, academic research on this topic is limited. TNO is conducting research for a longer period on construction logistics. Prior TNO research was conducted on large construction projects and a few medium construction projects. Those medium projects have been used for analysis in this thesis project.

9.3 RECOMMENDATIONS

Further research should be undertaken to gather quantitative data. This quantitative data can afterward be used to analyze the impact of logistics solutions on costs and benefits. The different sizes of construction projects (micro, small and medium) should be analyzed separately. An excellent way is to gather quantitative data by using pilot projects. The following variables were unknown in this thesis project and can help to make an analysis of the impacts of the logistics solutions:

- Personnel
    - The number of personnel working in a project.
    - The personnel disciplines (plasterer, carpenter, painter, etc.) active in the project.
    - Time working at a project.
- Transport movements
    - Number of transport movements during a project and the objective of the transport movements.
    - All suppliers of a construction project.
- Material
    - The material requirements on a project's time-scale. Which materials are ordered and used at which time?
    - The materials and quantity of those materials are needed as soon as possible (rush orders).
    - Load factor of supply trucks.
- Waste
    - The time waste is picked up from the construction site during a project.
    - Who picks up the waste.

Furthermore, to combine materials of different suppliers it is necessary to have universal data usage. Research in how materials can be converted into product specifications necessary to combine orders

can help to make it universal. An interviewed wholesaler mentioned the fact that they are continuously thinking about how to increase the load factor by analyzing their data and how materials can be combined in one truck. If this is done by an external party, that knowledge can be shared among the other wholesalers and transporters.

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APPENDIX I. LITERATURE REVIEW

Literature sources survey

The search for literature has been conducted mainly with the use of Google Scholar, Web of Science, Scopus and TU Delft Library. A useful method to witness the links between different papers is using the sources of a paper itself called the snowball effect. In this way, the link can be explained better and other useful papers could be found. Also, combinations of the terms or small variations (such as center or centre) have been used to find the literature. Preferably, refereed academic journals are used because they contain detailed information of state-of-the-art research so that you know the development of knowledge in the field. Furthermore, TNO published multiple reports about this problem situation.

The following terms have been used to search for papers: construction, logistics, transport, supply chain management, urban freight, city logistics, inner city building, construction consolidation centers, CCC, urban consolidation centers, UCC, construction project size, third party logistics, TPL, 3PL, fourth party logistics, FPL, 4PL, small and medium sized enterprises, SME, contractor, stakeholder, multi-modal, multi-criteria decision-making, multi-criteria analysis.

A literature review is needed to generate and refine research ideas and to be critical on the work performed in the past. The literature review is split up in different themes and starts with construction logistics. This is also the initial stakeholder identification and their position in the supply chain. The role of stakeholders is further developed in the second theme. Afterward a review is conducted about the possible solutions called best practices. A summary of all reviewed literature is presented in Table 20.

Construction logistics' supply chain

The organizations that are part of the construction logistics are manufacturers, wholesalers, brokers, dealers, contractors, building sites, owners, users and employers as shown in Figure 30. Construction logistics is to organize, plan, control and to carry out the supply and disposal of materials, equipment and personnel from and to the construction site. The logistics in the construction industry only began to gain more attention recently and academic research in the implementation of supply chain management in this field is scattered and partial (Gadde & Dubois, 2010). A main contributor to this weak implementation is that there is a low relationship stability because companies in the construction industry want to avoid dependence on other parties in the chain. However, a survey among contractors in the United Kingdom stated that 48% feels supply chain management is of critical importance, 42.5% feels it is importance and only 10% think it is limited or of no importance (Akintoye, McIntosh, & Fitzgerald, 2000). An often-stated problem is that industry practitioners do not recognize the importance of construction logistics because they mention that every construction project is a one of a kind where every time the operations needs to be readjusted or completely reconstructed (Ying & Tookey, 2014; Sobotka & Czarnigowska, 2005).

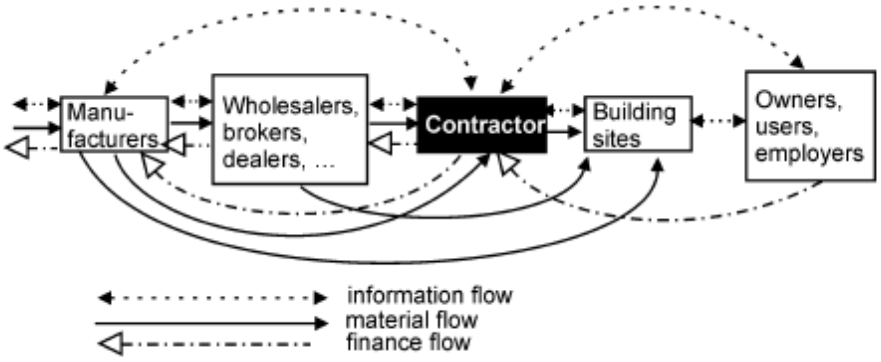

Figure 30: A building contractor within a supply chain of materials and participants of a project (Sobotka, Czarnigowska, & Stefaniak, Logistics of construction projects, 2005)

There are two classes in urban freight transport: consumer-related distribution and producer-related distribution (Guerlain, Renault, & Ferrero, 2018). The consumer-related distribution includes retail, food and home deliveries whereas the producer-related distribution includes construction materials, waste and industrial goods. This thesis project will focus on the second one: the producer-related distribution. The delivery vehicles for urban freight transport are delivering in two ways: single-drop trip and multi-drop round. Almost all deliveries for construction logistics apply the single-drop trip and not the multi-drop round where they deliver to several receivers. There is a difference in construction related transport flows that apply a single-drop trip and a multi-drop trip. In the early stage of a project singe-drop tips are most common and in the end stage of a project multi-drop trips can be applied.

Construction is taking place in urban areas increasingly due to urbanization. The available place to store supplies at construction sites within the urban areas is limited and therefore construction logistics are direct impacting the needed materials during construction. The logistics in urban areas is often referred to as last mile delivery because it is at the end of the supply chain. This part of the logistics process, the last mile, is less efficient and compromises a large amount of the total delivery cost (Wang, Zhang, Liu, Shen, & Lee, 2016).

Stakeholder involvement

Ballantyne et al. (2013) address the necessity of stakeholder involvement in urban freight. A stakeholder is a person, group or organization who can affect or is affected by the achievement of someone's objectives. A wide perspective to understand the complexity of the interactions between stakeholders helps urban freight planning and to propose suitable trade-offs between possible alternatives. In this way, the single-drop trips could be transformed to multi-trip rounds. This is further elaborated in partnering of stakeholders by Gadde and Dubois (2010). High involvement relations impose continuous transactions between buyers and suppliers. However, this is difficult in the construction sector because projects are considered one-off. Buyers usually switch from suppliers because they try to avoid dependence on specific partners. Partnering of stakeholders requires an analysis about the multi-stakeholder and multi-criteria situation. This analysis has been performed by Aljohani and Thompson (2019) but on regular urban freight and not in construction. The conclusion is that there is no single solution that could satisfy all stakeholders' objectives. A list of criteria needs to be defined in order to evaluate logistics initiatives (Awasthi & Chauhan, 2012).

The announced zero-emission zones are not the only policy measure that can and is undertaken. Another measure is the regulation of access and freight delivery times (Lu & De Bock, 2015). These

policy measures try to achieve the triple bottom line of sustainability: creation of economic value, clean environment and livability for society.

Construction logistics solutions

First, the terminology used in this report will be explained to clarify the meaning. The term construction logistics structure is the entire list of logistics structures undertaken for a construction project. Construction logistics solutions are smart solutions to improve the efficiency of a part of the construction logistics structure. An example is carpooling where the personnel of a construction project are bundled instead of driving separately towards the site. All construction logistics solutions found in literature are summarized in Table 20.

Organization TNO is conducting research about construction logistics in urban areas during the past decade and are searching for the impacts of new logistics concepts. TNO has found a wide set of best practices to improve construction logistics that is not found in other academic research. The start of new construction logistics solutions is found in the report of Quak et al. (2011). In this report, the flow of transport for construction projects has been distinguished into separate groups (see Table 19). These different types of flows are the start of searching for a new logistics solutions because every transport flow has its own characteristics that can be improved in its own way. For example, a full-truckload (FTL) is fully packed and therefore bundling of materials is not possible for this transport flow whereas for all other transport flows bundling will decrease the number of transport movements.

Dijkmans et al. (2014) applied models to evaluate different scenarios about a renovation project in Amsterdam 'De Singel' of €1.4 million. The scenarios are based on different solutions for construction logistics. The number of delivery trips can be decreased with only 0.04% – 1.19% of additional costs based on total costs. Mentioned here is that because of the smaller size of this renovation project the desired reduced logistic costs has not been achieved. With an upscale that includes additional similar projects (Keizerstraat, Prinsenstraat and Singelstraat) lower logistic costs can be reached. This economy of scale delivers more synergy for traffic flows because material can be bundled better.

Another report by Klerks et al. (2012) identified a list of logistics solutions and suggested some of these to an evaluation of an analyzed project in the Hague that was composed out of five SME subcontractors. TNO is also working on a project to move transport from the road to water called 'Amsterdam Vaart'. This logistics solution is the use of other modality transport. The number of transport movements is reduced significantly with this best practice for four different cases (TNO, 2019) and therefore can be called a best practice. This best practice is not applicable for all areas but for Amsterdam most of the future construction projects are accessible by water for transport of building materials and return flows such as construction waste.

Table 19: Transport flows in construction (Quak et al., 2011)

Transport flow	Construction phase	Description
Full-truckload (FTL)	Shell	The transport of materials by trucks are fully loaded. The materials are delivered directly from the supplier. This is often the case with raw materials such as concrete, sand or stones. There are two types of FTL flows. The first is time-critical FTL flow that needs to have material at a specified time in which concrete is the most common flow. The second is a non-time critical FTL flow where a specified delivery time is not important. Examples of this type are isolation material and piles.
Less than truck load (LTL)	Shell, completion	The transport of materials by trucks are not fully loaded. It is difficult to fill the load with other materials when materials cannot easily be stacked or strange shapes.
Packages	Completion	Smaller sized LTL streams that are not placed on pallets. Delivery vans usually deliver this transport flow.
Rush orders	Completion	Rush orders are used when the project suddenly needs certain material. This is a time-critical alternative of the LTL streams thus pallets and packages. Usually, these orders

		are more expensive but the costs are lower than having absent materials that causes delay.
Returns	Shell, completion	Returns are the flow from the construction site. This is an enormous flow for demolishing activities of concrete, debris or ground material. There are also return flows such as packaging waste, wrong deliveries, damaged deliveries or non-usable materials.
Equipment	Shell, completion	There are two types of equipment: large and small equipment. Large equipment are heavy duty tools such as cranes. Small equipment are the tools that subcontractors and freelancer transport with themselves.
Personnel	Shell, completion	The transport of people that are working on the construction site.

Table 20: Summary of all literature used for literature review

Author	Title	Description	Theme
Guerlain, Renault & Ferrero (2018)	Urban Freight: What about construction logistics?	The difference between construction logistics and other supply chains (retail, HoReCa, home deliveries). An analysis of 4 construction sites. The projects are large and they mainly use heavy good vehicles.	Construction logistics
Ying & Tookey (2014)	Addressing effective construction logistics through the lens of vehicle movements	Case study about trucks driving to the construction site. They are evaluating efficient construction logistics to decrease the logistic costs. However, before that they interview main contractors, subcontractors and material suppliers about how the process is organized so that they have an insight about the inefficiencies. The location of the site was in a city, in New-Zealand.	Construction logistics
Sobotka & Czarnigowska (2005b)	Analysis of supply system models for planning construction project logistics	Linking supply chain, or logistics, with construction. They analyzed a Polish construction project on different aspects of logistics.	Construction logistics
Sobotka, Czarnigowska & Stefaniak (2005a)	Logistics of construction projects	Basic explanation about the definition construction logistics. All stakeholders are mentioned and their relations visualized.	Construction logistics
Gadde & Dubois (2010)	Partnering in the construction industry – Problems and opportunities	Partnering between various stakeholders can help to improve construction efficiency and performance. Institutionalized norms and behavior in construction is the main issue why projects usually are decentralized and why the tendering is competitive. But it is explained that buying firms would benefit considerably from enhanced interaction.	Construction logistics/ Stakeholder involvement
Akintoye, McIntosh & Fitzgerald (2000)	A survey of supply chain collaboration and management in the UK construction industry	A survey on the opinions of contractors in the UK on supply chain collaboration. The contractors are groups into three groups based on their size: large, very large and mega large.	Construction logistics/ Stakeholder involvement
Awasthi & Chauhan (2012)	A hybrid approach integrating Affinity Diagram, AHP and fuzzy TOPSIS for sustainable city logistics planning	An evaluation of city logistics with the use of a multi-criteria multi-stakeholder approach. The stakeholders used in their research are shippers (wholesalers), transport companies (carriers), receivers (shop owners), end-consumers (city residents, tourists) and public administrators. This is very similar to the construction logistics where the receivers are not shop owners but contractors.	Stakeholder involvement
Ballantyne, Lindholm & Whiteing (2013)	A comparative study of urban freight transport planning: addressing stakeholder needs	Not about construction logistics in cities but about general urban freight transport. The problem that they highlight is that the understanding of the stakeholder interactions are crucial for efficient urban logistics.	Stakeholder involvement
Osypchuk & Iwan (2019)	Construction site deliveries in urban areas, based on the example of Szczecin	General explanation about construction logistics to urban areas. An analysis is made about the different types of procurements a contractor can apply and advantages and disadvantages about the procurements are explained. The type of procurement is an important element of logistics construction projects.	Stakeholder involvement

Lu & De Bock (2015)	Sustainable Logistics and Supply Chains: Innovations and Integral Approaches	A book about the innovations of sustainable logistics. It describes the total supply chain in detail and where possible solutions lie.	Stakeholder involvement
Quak et al. (2011)	Solutions for construction logistics for inner city construction	The main start of the research by TNO to analyze construction logistics. The analysis came up with a list of solutions that can improve the logistical process. These solutions are relevant for future research to assess the applicability.	Construction logistics solutions
Dijkmans et al. (2014)	Cooperation in Amsterdam's construction logistics	One large case study about a construction project in Amsterdam at 'De Singel'. This is a relevant case study because of its size based on construction costs of €1.4 mln. Furthermore, they came up with a systematic approach to form and manage alliances. However, they do recognize that alliances are failing 40-60% with many diverse causes.	Construction logistics solutions
Klerks et al. (2012)	Construction logistics: crucial in efficient and sustainable construction	An analysis about cooperation, management and logistic solutions in the construction. A case study in the Hague with one contractor and five SMEs subcontractors is monitored in terms of their transport flow. Logistic solutions are proposed to improve the flows. Most of the transport is personnel based.	Construction logistics solutions
TNO (2019)	'Amsterdaam Vaart': findings 2018	There are four different use cases under monitoring. This project is not yet finished so these are intermediate results. The cases are in Amsterdam are all located close to a waterway, which is common in Amsterdam.	Construction logistics solutions
De Bes et al. (2018)	Duurzame Bouwlogistiek voor Binnenstedelijke Woning- en Utiliteitsbouw	An analysis of nine construction projects called 'proeftuinen'. A list of logistics structures has been provided and the projects used from these. There is also a detailed description about what sustainable construction logistics is.	Construction logistics solutions
Van Merriënboer & Ludema (2016)	TKI project '4C in Bouwlogistiek'	A project has been monitored called 'De Trip' in Utrecht. Several best practices have been used and key performance indicators (KPIs) are used to measure these best practices.	Construction logistics solutions

APPENDIX II. LOGISTICS SOLUTIONS

Table 21: Solutions for construction logistics (Van Merriënboer, Vrijhoef, Ludema, & De Vries, 2013; De Bes, et al., 2018; Klerks, et al., 2012)

Logistics solution	Applications	Description	Source
Building ticket	Either a physical or digital ticket. A digital ticket requires an ICT solution.	This is a tool to coordinate the flow of materials and to have a JIT supply. This is a form a pull oriented process. Almost always in combination with hubs and logistics transport coordinator.	Van Merriënboer et al. (2013), De Bes et al. (2018)
BIM (building information model)	Digital model in 3D made by architects.	Architects can choose to make their design in BIM and therefore in 3D instead of the usual 2D. Information exchange is faster in this way and the design can be coupled to the logistics planning of contractors, subcontractors, suppliers and logistics service providers.	(Van Merriënboer, 2016)
Clustering personnel	-	Clustering of personnel at the outskirts of a city, can be a hub, to take transport together instead of going with separate transport. This reduces the number of transport movements but also the problems with parking place and parking costs. The transport to cluster the personnel is public transport and possibly a shuttle service. Another term used for this best practice is carpooling.	Van Merriënboer et al. (2013), De Bes et al. (2018), Klerks et al. (2012)
Construction consolidation center	Location of the 'hub' can be at the outskirts of city center, on the construction site or at the source of the supply chain. The scope can be different. It can be used for one project only or for more projects. The owner of the hub can different. It can be owned by the main contractor, logistics service provider or a supplier.	The consolidation center operates as a transfer point from outer city to inner-city transport when positioned at the outskirts of a city center. The goal is to bundle the materials as much as possible to maximize the load factor of the trucks. This transfer point disconnects outer city and inner-city transport. Suppliers can bundle their transport when the hub is at the source. Bundling at the source can be stimulated when contractors buy in locally so that they are close to each other. A hub at the construction site is to create work packages to improve internal logistics.	Van Merriënboer et al. (2013), De Bes et al. (2018), Klerks et al. (2012)
Cross Chain Control Center (4C)	Can be integrated with different ICT systems. A pilot project in Utrecht called 'de Trip' has used this best practice (Van Merriënboer & Ludema, 2016).	Chain control of all construction related transport flows from and to multiple construction sites. Insights of construction chain processes are created from all available data from the integral chain handed over by all chain stakeholders. It is an extended form of a logistics transport coordinator.	Van Merriënboer et al. (2013)
Deliver outside construction time	-	The supplies are normally delivered during rush hour. The deliveries during rush hour is not always necessary.	De Bes et al. (2018)
Innovative building	-	The construction process is changed by itself to realize improvements in the logistics process. A widely known innovation is prefab (prefabricated construction parts) that are built before transport to reduce the activities at the construction site. Another complex innovation that can be useful is 3D printing.	Van Merriënboer et al. (2013), De Bes et al. (2018), Klerks et al. (2012)
Integral distribution network	-	The coordination of the distribution network based on sources and destinations. The idea is to couple suppliers and construction sites in such a way that the delivery takes place from the nearest location.	Klerks et al. (2012)
Lean construction	Has been applied to smaller renovation projects.	The design of the logistics process in such a way that the construction activities at the construction site can take place as effective and efficient as possible. It is the application of lean philosophy in the construction sector. Examples of this philosophy are 5S-model and lean six sigma.	Van Merriënboer et al. (2013)
Logistics transport coordinator	Applied to one construction project/site or multiple.	An external person assigned for coordination of supply and disposal of materials from and to the construction site. This fourth party logistics service provider (4PL) is responsible for a good connection of the supply of materials with the construction	Van Merriënboer et al. (2013), Klerks et al. (2012)

		process. His goal is to minimize the stock at the construction site and to apply just-in-time deliveries. Often, in combination with hubs and building tickets.	
Mobile stock container	Examples are the Mobile Service Unit of Technische Unie and the 'afbouwbox'.	A movable container used for transport, storage and stock control of materials on the construction site. The application of this container results in stock control that can prevent unnecessary failure costs.	Klerks et al. (2012)
Material container	Is placed on or near a construction site.	A container, or collection point, where small goods or materials can be picked up directly when they are needed if they are not available at the construction site. This solution will create synergy in supply and transport costs if multiple construction sites are combined.	Klerks et al. (2012).
Combi container	-	This is a container that is composed out of two parts. Return flows can be collected in one part and supplies can be stocked in the other part.	Klerks et al. (2012)
Other transport modality	Transport over water of on rails.	Alternative transport modalities than normal road transport of materials, equipment and personnel.	Van Merriënboer et al. (2013), De Bes et al. (2018), Klerks et al. (2012)
Other transport type	-	This is the use of other transport types to reduce the emissions. It can be that change towards electric vehicles or to bike deliveries.	De Bes et al. (2018)
Planning system	-	The different steps in the process of transport towards and on the construction site can be better connected with each other with the use of a planning system. A building ticket is an example of a planning system. Other planning systems are the planning of vertical transport because that is often a bottleneck at a construction site and to include construction logistics into the start of the day with clear communication.	De Bes et al. (2018)
Preference network construction traffic	-	Transporters choose for the most efficient route and not for the prescribed route. Municipalities want the transporters to take the prescribed routes and can oblige them with the use of traffic signs and enforcement.	Van Merriënboer et al. (2013), Klerks et al. (2012)
Runners	At the construction site.	Personnel at the construction site only assigned to move the material at the right place at the right time. In this way, specialists can concentrate on their own job and not on finding the right material and equipment. This is an improvement of internal logistics because it is on site.	De Bes et al. (2018)
Smart return	-	Construction leads to a large amount of waste. This waste needs to be taken away and the faster it happens the better because waste reduces the space available at the site.	De Bes et al. (2018)
Supplied Managed Inventory	-	Order and distribution system for delivery within 24 hours.	Van Merriënboer et al. (2013)
Waiting area for deliveries	Construction sites that have no or limited space to store supplies.	Just-in-time deliveries reduce the storage of supplies at a construction site. An extension of the storage is possible to set up a waiting area. In this case, vehicles do not need to drive around waiting until there is space available at the construction site to deliver the supply.	De Bes et al. (2018)

APPENDIX III. INTERVIEW PROTOCOLS

This is the general structure of the interview protocol. The interviews were conducted to the stakeholder groups contractors, wholesalers, transporters, a CCC and a municipality. The questions formulated in this protocol cannot be answered by each stakeholder. Furthermore, the interviews were conducted together with Hogeschool Rotterdam so the set-up was a combination of their questions and these.

- Introduction
  - On behalf of TNO and for master thesis at TU Delft research into construction logistics small-scale construction projects by SMEs
  - A lot of research on large projects, little on a small / medium size
  - Objective: to develop new construction logistics concepts specifically for small-scale construction projects (many in number, less large volume of construction flows) that can contribute to Green Deal Construction Logistics objectives.

- Intro questions:
  - Who are you and what is your role within the company?
  - What does the company you work for do?
  - What is the role of the company in the construction logistics chain?
  - In which area is your company active?

- Construction projects and logistics
  - In the large-scale construction projects, you will see a phasing in the construction process: shell construction - rough finishing - finishing with also clear differences in transport flows. What about small-scale construction projects?
  - Could you tell us something about your order and delivery process?
  - What do you do yourself and what do you outsource?
  - Are smart construction logistics concepts / measures already being applied? See for example:

Stock container	Clustering personnel	Runners
Deliver outside construction time	CCC	Smart return
Logistics transport coordinator (4PL)	Other modality	Prefab

  - What are the trends and developments in renovation?
  - What is the difference between new construction and renovation in the use of building materials in this category? Can you provide examples of (recent) construction projects?
  - How do small and medium-sized contractors work and what is the difference in ordering behavior / transport of building materials between small and medium-sized?
  - What is the role of freelancers in small-scale construction projects? How do they work and what is the difference in ordering behavior / transport of building materials between SME contractors and freelancers?
  - What is your experience with bundling building materials from other suppliers (positive / negative, room for improvement)?
  - In terms of equipment, what do you own and what do you hire?

    - How much will your staff go to the wholesaler in between to collect some items? And what about the subcontractors? How do you prevent this?
    - Are there rush orders? How often? does this differ between small and large construction projects?
    - What materials are brought in with emergency rides?
    - What is the load factor for rush trips?

- Cooperation
    - Do you use outsourcing of transport (external logistics service provider)?
    - With which parties, do you cooperate in the chain? How is that collaboration?

- Logistics services
    - Do direct deliveries from producers / manufacturers mainly take place for large projects and not for smaller construction projects? Why?
    - How much do you use construction hubs, and how do you use them (storage)?
    - Do you use outsourcing of transport (external logistics service provider)?

- Transportation costs
    - Do you have good insight into your transport costs?
    - Are transport costs explicitly charged (separately)? and if so how much?
    - Are these transport costs an obstacle for contractors?
    - Are you trying to make it attractive for contractors to pick up their order? Or are you aiming to deliver from wholesalers as much as possible?

- Zero measurement
    - In order to gain an idea of the current logistics process of small-scale construction projects, we would also like to quantify (numerical estimate) the logistics construction flows of typical small-scale construction projects. Can you provide numerical material / make numerical estimates of the discussed construction logistics flows?

APPENDIX IV. GROSS FLOOR AREA

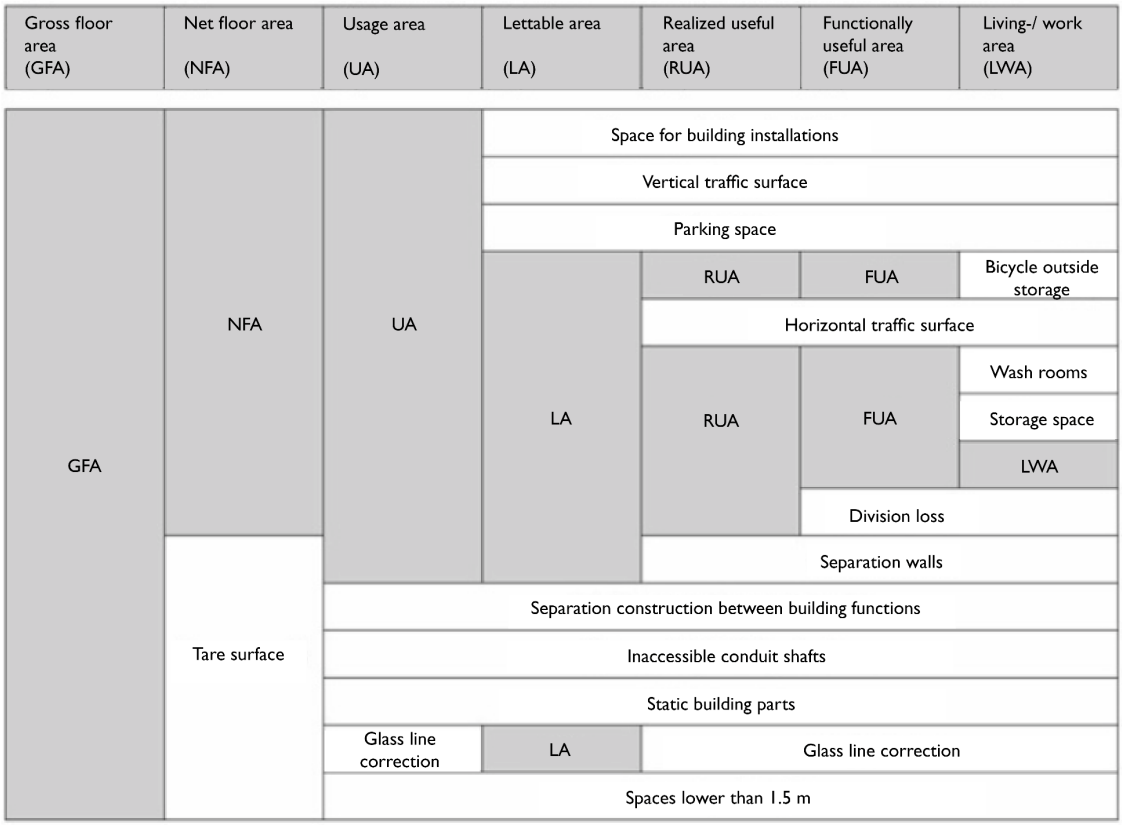

Figure 31: Composition of gross floor area (Kantorenwizard, n.d.)

APPENDIX V. PURCHASE PRICE DELIVERY VANS

Table 22: Most sold delivery vans (ANWB, 2020; Bestelauto, 2020)

Delivery van	Electric	Purchase price, taxes excluded (€)
Mercedes-Benz eVito	Yes	41,990
Nissan e-NV200	Yes	32,020
Renault KANGOO Z.E.	Yes	28,365
Renault Master Z.E.	Yes	63,500
Volkswagen e-Crafter	Yes	56,700
Volkwagen Transporter	No	23,600
Mercedes-Benz Sprinter	No	20,990
Volkswagen Caddy	No	13,150
Ford Transit Custom	No	23,425
Mercedes-Benz Vito	No	18,990
Opel Vivaro	No	17,999

APPENDIX VI. WHOLESALER'S CUSTOMER DATA

Customer 1

Table 23: Customer 1 data on pickup or delivery orders and one-directional travel time to nearest wholesaler

Residence number	Orders pickup	Orders delivery	Pickup/delivery	Travel time nearest wholesaler (min)
Residence 1	11	1	Pickup	7
Residence 2	4	0	Pickup	6
Residence 3	4	0	Pickup	6
Total	19	1	-	-

Customer 2

Table 24: Customer 2 data on pickup or delivery orders and one-directional travel time to nearest wholesaler

Residence number	Orders pickup	Orders delivery	Pickup/delivery	Travel time nearest wholesaler (min)
Residence 1	1	0	Pickup	7
Residence 2	4	0	Pickup	8
Residence 3	2	2	Pickup and Delivery	8
Residence 4	7	1	Pickup and Delivery	6
Residence 5	2	1	Pickup and Delivery	7
Residence 6	3	0	Pickup	4
Residence 7	3	1	Pickup and Delivery	8
Residence 8	11	0	Pickup	6
Residence 9	2	0	Pickup	10
Residence 10	1	0	Pickup	12
Residence 11	7	0	Pickup	8
Residence 12	1	0	Pickup	8
Residence 13	2	0	Pickup	10
Residence 14	3	0	Pickup	8
Total	49	5	-	-

Customer 3

Table 25: Customer 3 data on pick-up or delivery orders and one-directional travel time to nearest wholesaler

Residence number	Orders pickup	Orders delivery	Pickup/delivery	Travel time nearest wholesaler (min)
Residence 1	4	0	Pickup	1
Residence 2	0	4	Delivery	18
Residence 3	0	1	Delivery	18
Residence 4	0	2	Delivery	19
Residence 5	1	0	Pickup	8
Residence 6	0	8	Delivery	23
Residence 7	0	1	Delivery	41
Residence 8	0	6	Delivery	22
Residence 9	1	0	Pickup	6
Residence 10	0	1	Delivery	18
Residence 11	1	0	Pickup	2
Residence 12	1	0	Pickup	6
Residence 13	1	6	Pickup and Delivery	17
Residence 14	0	6	Delivery	6

Total	9	35	-	-

Customer 4

Table 26: Customer 4 data on pick-up or delivery orders and one-directional travel time to nearest wholesaler

Residence number	Orders pickup	Orders delivery	Pickup/delivery	Travel time nearest wholesaler (min)
Residence 1	1	0	Pickup	8
Residence 2	0	1	Delivery	7
Residence 3	1	1	Pickup and delivery	8
Residence 4	0	1	Delivery	7
Residence 5	0	1	Delivery	19
Residence 6	0	3	Delivery	27
Residence 7	0	1	Delivery	19
Residence 8	1	0	Pickup	8
Residence 9	0	1	Delivery	15
Residence 10	0	1	Delivery	20
Residence 11	0	1	Delivery	21
Residence 12	0	1	Delivery	8
Residence 13	0	1	Delivery	15
Residence 14	0	2	Delivery	6
Residence 15	0	1	Delivery	21
Residence 16	0	1	Delivery	8
Residence 17	0	2	Delivery	6
Total	3	19	-	-

Customer 5

Table 27: Customer 5 data on pick-up or delivery orders and one-directional travel time to nearest wholesaler

Residence number	Orders pickup	Orders delivery	Pickup/delivery	Travel time nearest wholesaler (min)
Residence 1	0	1	Delivery	18
Residence 2	2	1	Pickup and delivery	9
Residence 3	0	4	Pickup	7
Residence 4	6	3	Pickup and delivery	8
Residence 5	1	0	Pickup	15
Residence 6	0	2	Delivery	13
Residence 7	3	1	Pickup and delivery	7
Residence 8	1	0	Pickup	13
Residence 9	2	0	Pickup	10
Residence 10	3	0	Pickup	9
Residence 11	0	2	Delivery	6
Total	18	14	-	-

Customer 6

Table 28: Customer 6 data on pickup or delivery orders and one-directional travel time to nearest wholesaler

Residence number	Orders pickup	Orders delivery	Pickup/delivery	Travel time nearest wholesaler (min)
Residence 1	0	2	Delivery	13
Residence 2	0	5	Delivery	30
Residence 3	0	1	Delivery	12
Residence 4	0	1	Delivery	20
Residence 5	0	4	Delivery	22
Residence 6	0	1	Delivery	20

Residence 7	0	2	Delivery	20
Residence 8	0	9	Delivery	20
Total	0	25	-	-

Customer 7

Table 29: Customer 7 data on pickup or delivery orders and one-directional travel time to nearest wholesaler

Residence number	Orders pickup	Orders delivery	Pickup/delivery	Travel time nearest wholesaler (min)
Residence 1	0	1	Delivery	14
Residence 2	0	1	Delivery	14
Residence 3	0	1	Delivery	16
Residence 4	0	4	Delivery	21
Residence 5	0	5	Delivery	8
Residence 6	0	1	Delivery	15
Residence 7	0	1	Delivery	16
Residence 8	0	3	Delivery	27
Residence 9	0	6	Delivery	22
Residence 10	0	1	Delivery	29
Residence 11	0	4	Delivery	29
Residence 12	0	8	Delivery	22
Residence 13	0	3	Delivery	12
Residence 14	0	4	Delivery	15
Residence 15	0	5	Delivery	17
Residence 16	0	3	Delivery	35
Residence 17	0	3	Delivery	16
Residence 18	0	2	Delivery	18
Total	0	56	-	-

Customer 8

Table 30: Customer 8 data on pickup or delivery orders and one-directional travel time to nearest wholesaler

Residence number	Orders pickuup	Orders delivery	Pickup/delivery	Travel time nearest wholesaler (min)
Residence 1	0	1	Delivery	26
Residence 2	0	3	Delivery	17
Residence 3	0	2	Delivery	10
Residence 4	0	6	Delivery	11
Residence 5	0	2	Delivery	10
Residence 6	0	3	Delivery	30
Residence 7	0	1	Delivery	10
Residence 8	0	3	Delivery	19
Residence 9	0	3	Delivery	15
Residence 10	0	13	Delivery	26
Residence 11	0	3	Delivery	24
Residence 12	0	13	Delivery	28
Residence 13	0	2	Delivery	19
Residence 14	0	1	Delivery	30
Residence 15	0	1	Delivery	18
Residence 16	0	2	Delivery	17
Residence 17	0	7	Delivery	15
Residence 18	0	2	Delivery	41
Total	0	68	-	-

Ratio of pickups/delivery

Table 31: Ratio of customers' pickups/delivery. The total is based on the ratio of all orders and the average is based on customers' ratio

Subject	Ratio pickups /delivery
Customer 1	95%
Customer 2	91%
Customer 3	20%
Customer 4	14%
Customer 5	56%
Customer 6	0%
Customer 7	0%
Customer 8	0%
Total	31%
Average	35%

APPENDIX VII. HUB CONCEPTS

A CCC is an application of a 'hub' that is a distribution facility that is used in the process of managing project logistics, channeling material deliveries to a single or multiple construction sites (Designing Buildings, 2017). A hub is a distribution center (DC) that improve last mile deliveries on distance driven in urban areas and emission reduction. Hubs can be operated by different stakeholders but their mission is the same. There are hubs operated by large contractors, wholesalers and transporters. One interviewed transporter has its establishment in Amsterdam Noord close to the city center and started to use the term 'hub' recently because this reference is hot these days. Examples of CCCs are Bouwhub Amsterdam, Volker Wessels' CCC in Utrecht and Stockholm's Building Logistics Center (BLC). Research have shown that the amount of transport movements to the construction site can be reduced by 69% while using Volker Wessels' CCC in Utrecht (Van Merriënboer & Ludema, 2016). Bouwhub Amsterdam is an independent organization, called a white label, that only focusses on the logistics of construction projects. This organization is part of a transport company. The white label concept implies that all parties can make use of the facilities the CCC offer.

An interview with Bouwhub Amsterdam gave insights in the operations of a CCC, how they help with improving efficiency and why they can act as a useful logistics solution. Their key activities are storage, transport, advice and transshipment. Many people think that a CCC cannot be of use in the shell construction. However, that is not the case. Bouwhub Amsterdam operates a significant amount in shell construction phase. Materials such as styrofoam, click floor slabs, beams, sandwich floor and reinforcing steel arrives in bulk at the CCC. The advantage is that these shell construction materials are delivered at the site together with loose deliveries. These quick and small orders such as little boxes, screws, battens, pur foam or drywall are picked up at the wholesaler to fill up the truck. Bouwhub Amsterdam is a white label and does not have interest in sales of construction materials. They know and cooperate with all wholesalers without giving priority. The main goal is to support the final customer which is the main contractor and to unburden the city's traffic.

The transport organized by Bouwhub Amsterdam is outsourced to the transport company where they are part of. Approximately 10-15% is outsourced to other transport companies that will increase in the future. They do not own vehicles because starting a transport company nowadays has no sense because of the high level of competition and the demand for vehicles is fluctuating. Some days ten vehicles are needed and other days only three. This type of outsourcing is called chartering.

Bouwhub Amsterdam identified that the material return flows that are taken back are mostly parts that are stackable. Examples are boxes, dormers and doors. The new parts arrive at the site on roller cages. Afterward, the old parts are stacked on the empty roller cages. Pallets are also taken back because these still have value. Waste such as concrete or debris are not transported back. That kind of waste needs to be thrown away in a waste container. The examples given show that the return flow is limited.

Small-scale construction projects can be assisted with a CCC. It does not matter if the drawings are flat (2D) or if it is a BIM model, eventually what must be known is how many materials are needed for each house or floor. This information is available. However, it is not as detailed for 4D planning but that is not necessary. Small projects need to have a planning to obtain a permit and to be accepted by the client. Therefore, the use of hubs is an excellent logistics solution. The implementation for micro

projects is unfeasible because the amount of material is not enough. Small and definitely medium sized projects are eligible for the use of CCCs.

APPENDIX VIII. EXTENDED STAKEHOLDER ANALYSIS

Step 1: Problem formulation

Initially, the problem owner is the Dutch government. The government had signed the Paris Agreement with the goal to reduce greenhouse gas emissions by 49% (Overheid, 2019). At the point of signing it was their problem how to reach this reduction. Afterward, the government developed a national climate agreement to enforce the society in reducing their emissions. From that moment, the problem owner was transferred towards the people responsible for emissions. In the case of this thesis project, the contractor becomes the new problem owner. Contractors are the managers of a construction project and responsible for decisions made. The legislation made by the government is that there will be Zero-Emission zones from 2025 for all vehicles except EURO VI trucks and from 2030 for all vehicles. The construction logistics is either performed by (sub)contractors themselves or outsourced. In both cases, it is logistics that is needed for them so that the construction can take place. This defines the problem because clients, and therefore contractors also, are not willing to pay more for more sustainable logistics but they need to be sustainable in the near future.

Step 2: Inventory of actors involved

An inventory of actors and acknowledging the different problem definitions they all have, can shift the initial problem formulation. That means that other stakeholders can become relevant for a solution of the problem. The stakeholders identified are generic and not specified because the problem situation applies to 30-40 municipalities. Within the construction supply chain there are three main groups of stakeholders. These are the suppliers, logistics service providers and constructers. The materials' supply for the constructers can happen in three ways. The first is that the constructers can transport the materials themselves straight from the suppliers or let the suppliers deliver. The second is the delivery of materials managed by an external transporter. And the third is that the material is delivered with the CCC as a transfer point.

Main contractors

The main contractor is the one who accepts the construction project and takes the responsibility to realize and coordinate the desired outcome. Communication towards all stakeholders throughout a construction project is done by main contractors. They can either choose to outsource the work to subcontractors or do it themselves. If they do it themselves the project is called turnkey. In that case, the entire project management is undertaken by the main contractor. Possibly, the main contractor is active as project developer. In this case, the goal is to bring in work and to sell it with a profit afterward.

Subcontractors

Subcontractors are independent so not employed by the main contractor. They are hired to either carry out the construction project entirely or partly. Mostly, the subcontractor is specialized in activities such as piling, painting, tiling or plasterers. It differs for each project if the contractor or subcontractor is responsible for procurement. In the Netherlands, 83.7% of working people in the construction industry are freelancers. SME contractors often hire freelancers as subcontractors.

Wholesalers

The suppliers of all sorts of material needed for construction. This can be building materials, wood, sanitary ware, tools, fasteners, electricity, lighting and paint. Wholesalers can also provide the logistics service to deliver the purchases to the construction site. Their production and inventory process is make-to-stock.

Manufacturers

They sell raw materials or produce construction products. These products could be sold to wholesalers who will act as a trader and sell it afterward. It can also be bought and delivered straight or with a logistics service provider to the constructers. In 2018, about 20% of the construction purchases have been made at the manufacturer (Goedhart, n.d.). Furthermore, manufacturers are capable of customer specific tailor-made products. Customers can place an order with a manufacturer that will be made exactly as described in the customer's specifications. This production and inventory process is make-to-order.

Transporters

An external party who is responsible for the transport and warehousing of materials. Also, called third party logistics (TPL or 3PL) because a third party acts as an intermediary between two supply chain companies. Transporters are focused on logistics and therefore on information activities. Tracking and tracing of materials, supplying ICT tools for planning and reverse logistics can be performed by the transporters (Shaharudin & Zailani, 2014). In order to remain competitive and relevant the transporters need to be innovative. The purchase of emission free trucks is such a way. Their operations is logistics only and offering a ZE alternative makes them more attractive, especially in the future.

Municipalities

Municipalities set frameworks for welfare policy, spatial development, tests the submitted building plans, issues the construction permits and carries out the required procedures. Municipalities can operate in four different roles: main client, licenser, coordinator and owner of the ground. The ZE zones will be applied to 30 to 40 municipalities and these are therefore the municipalities that are the part of this stakeholder group.

Architects

Architects are the designer of the end-product of the project. It could be that the architect is part of the contractor's organization. However, this is highly unlikely to occur at SME contractors. Otherwise, the design of the project is outsourced to an architect/designer where they play as an intermediate person between the client and contractor. The architect determines what construction processes needs to be performed. With their knowledge, they come up with an initial cost estimate.

Construction work planner

The management of what needs to be done before the project starts is performed by a construction work planner. The planning of construction work and the number of people, materials and heavy equipment is done by a construction work planner. The construction work planner is an employee of the main contractor. The smaller the contractor's enterprise becomes, the more the construction work planner will need to execute. Furthermore, the construction work planner outsources the work that needs to be performed to subcontractors. The number of people, materials and heavy equipment needed is therefore not known by the construction work planner.

Clients

Clients are the initiators of the construction project. They can either be a single person but also be an association, foundation or enterprise. Examples of clients are private house owners, municipalities, real estate investors, instances, housing corporations and project developers. They communicate with the contractors or architects what their desires are. There are mainly three groups that own the most rental houses. The largest group of house owners in the Netherlands are housing corporations with 2.3 million rental houses (Van den Eerenbeemt, Frijters, Kreling, & Van Uffelen, 2019). The second group are the large institutional real estate investors with 160,000 houses. These are companies that invest money of pension funds and insurers in real estate. The third group are the private owners that own 615,000 houses. These three groups own rental houses and next to rental houses are the owner-occupied houses which are 4.5 million houses in total (CBS, 2020).

Local residents

Local residents are the residents living in urban areas. This can either be in the city or close to the construction site. The residents' safety, livability and health can be affected while living in the city by construction logistics. The livability is improved by increased flow of traffic and decreased level of noise with fewer transport movements of construction logistics. The local residents can be represented by a tenants' organization or residents' committee. The difference between those is that a tenants' organization represents a larger field of one or more tenants than a resident's committee.

Construction consolidation center (CCC)

A construction consolidation center is a logistics service provider. Their establishment are located on the outskirts of the city and can coordinate and monitor the construction logistics. Materials can be stored here and transported to the construction site when needed. Value-adding activities such as kitting and assembly work can take place at a CCC. Clustering of personnel is also possible at a CCC. The personnel park their car there and are commuted to the site. Initially this stakeholder was considered one of high interest. However, during the interviews it became clear that a CCC can be managed by a variety of stakeholders. Bouwhub Amsterdam is a white label and can be considered as a separate CCC. It is still considered as a stakeholder in this inventory of actors involved. However, it is not analyzed further as an important stakeholder because other stakeholders can represent a CCC.

Research institutions

The research institutions are universities and research companies. Universities have interest in optimizing construction logistics because of the positive impact it delivers to society. Research companies can be hired by stakeholders to conduct research and consult them with plans of action.

Environmental NGOs

The Paris Agreement and Dutch climate agreement are both examples of what influence environmental non-governmental organizations (NGOs) have on legislations. Their goals are that climate agreements will be achieved in the future such that climate change will be reduced.

Step 3: Mapping formal relations

The relations between stakeholders have a formal and an informal side. The first step is to map the formal relations because it is more easy to reconstruct and it can help with mapping the informal relations on basis of hierarchical relations. A formal relation can be described as describing the formal

position of a stakeholder and their tasks and responsibilities, as specifying formal relations between stakeholders and as describing the most important laws (Enserink, Hermans, Thissen, Koppenjan, & Bots, 2010). The informal relations return in step five where informal resources are analyzed.

Tenants organizations and resident's committees have the right to information from landlords (Rijksoverheid, n.d.). This right allows them to obtain information about plans for demolishing homes, maintenance of homes and rental prices. Tenants commit themselves with landlords by a rental agreement (Gubbels, n.d.). There are multiple conditions in rental agreements but the most relevant to construction logistics is the condition about maintenance. Minor repairs need to be carried out and paid by tenants and the major repairs by landlords.

A building contract is the agreement between contractor and client to carry out a work of physical nature outside employment (Bouwrecht Advocaat, n.d.). This means that the contractor is the manager of the project but can outsource work to subcontractors. There are two ways how the costs are paid by the client. It can happen with a fixed price or on base of direction. For the base of direction, the contractor receives the compensation for the true made execution costs such as materials and wages plus increments for overheads and profits (usually around 10%). The outsource of work by contractors to subcontractors is made formal with a subcontracting agreement.

Almost all construction projects need to have a planning permission. This is a permit issued by the municipality where construction takes place. Next to the planning permissions, there is the BLVC-document (English: Accessibility, quality of life, safety and communication) that municipalities can add as a condition for the planning permission. The BLVC-system lets clients and constructers come to agreements that are in favor for the surroundings by limiting nuisance. Local residents have high demands related to construction activities. If too little thought is given to the consequences of a spatial intervention it will lead to misunderstanding from the residents and entrepreneurs that in worst case could lead to injuries or economical damage. That is because security services cannot reach their destination on time or customers are not coming to the entrepreneurs' stores due to the lack of accessibility. BLVC tries to create a balance between building safe and efficient and keeping the environment accessible, livable and safe. The municipalities Amsterdam and Utrecht already have the requirement that a proper BLVC-document is made before they issue a permit.

The situation that a contractor or wholesaler outsources the transportation to a logistics service provider is based on a contract. Prior to the contract is a letter of intent to connect the organization with the logistics service provider. This letter of intent is to provide the logistics service provider with exclusivity: in other words, the logistics service's seller commits himself to do business only with the logistics service's provider. From a legal point of view, transport and other activities, such as warehousing, are separated because the transport law (Dutch: *vervoersrecht*) falls under mandatory civil law from which both parties may not deviate (Logistiek, 2006). The transport law regulates that damage caused during transport is the responsibility of the transporter unless the transporter can prove that the caused damage is beyond control. The other activities in the logistics process must be defined as precisely as possible in the contract. This law can also be applied on suppliers when they take care of transport. Next to the building contract, are the building specifications made by the architect. What is going to be built and which construction activities are necessary are explained in the specifications. More specific, all technical and legal provisions and choice of materials are included. SME contractors therefore have limited to no control in what materials they use. UAV (English: Uniform administrative conditions) 2012 are used for the administration of the building specifications and regulate the relationship between client and contractor (Geertsema, 2014).

Other permits that contractors are exposed to are ISO 9000 and VCA (English: Safety, health, environment checklist contractors). The permit ISO 9000 developed by the NEN (English: Dutch Standard) is the international standard for quality management systems and shows that the company is working on continuous development. This permit is not obligatory to have but is strongly recommended by the government. The VCA is there for employees and supervisors of companies who execute risky activities. The construction sector is a sector with risky activities that has accidents on the site because of working on heights and with heavy and large equipment and machines. The VCA is certified to the contractors. Employees need a base-VCA diploma that is most of the times required to work for a contractor. Since 1 January 2016, a VOL-VCA (English: Safety for operational supervisors) is required for supervisors.

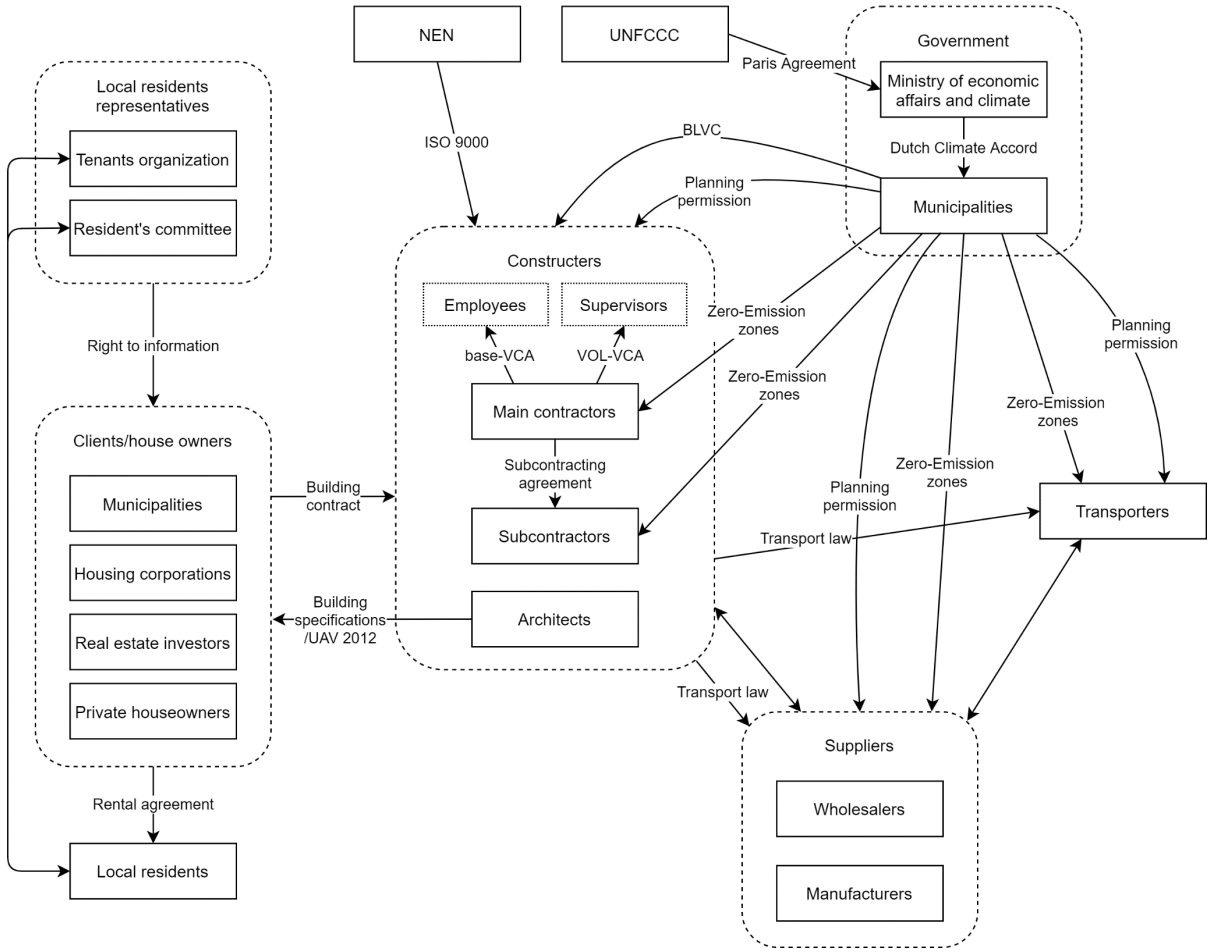

Figure 32: Formal relationship chart

Step 4: Problem formulations of stakeholders

An analysis based on the stakeholders' interests, objectives, causal beliefs and perceptions is used to derive the problem formulation of each stakeholder. Not all stakeholders found in the stakeholder inventory (step 2) are included in the rest of the analysis. Also, wholesalers and producers are taken together as one stakeholder which is the suppliers. All the problem formulations combined lead to the problem situation. The interests are the issues of most importance to a stakeholder. Interests are generic and not directly linked to the problem situation. Identifying the stakeholders' interests help with estimating how likely they will accept certain objectives or solutions. Objectives are more specific and indicate what stakeholders try to achieve. These objectives are used to judge the existing situation

and analyze the gap between that perceived existing situation and the desired situation. The larger the gap, the more serious is the problem. Perceptions are the images stakeholders have of the world around them on policy making context and on the policy problem and its characteristics (Bots, Van Twist, & Van Duin, 2000). Perceptions are necessary in stakeholder analysis because it is not possible to determine who is right in complex multi-actor problems.

Table 32: Problem formulations of stakeholders

Stakeholder	Interests	Objectives	Existing or expected situation	Possible solutions
Main contractors	Complete construction project	On time delivery of building, reduce costs, compliance to specifications	Zero emission transport too expensive, partly busy with ZE zones and decreasing transport movements	Financial and technological support to switch to ZE vehicles or outsource transport to third parties. Stimulate own personnel to carpool. Provide tools (equipment) to subcontractors.
Subcontractors	Complete part of construction project	On time delivery of task, reduce costs, compliance to specifications	ZE transport too expensive, not busy with ZE zones and decreasing transport movements	Financial and technological support to switch to ZE vehicles. Easy to arrive at destination with their necessary tools without own transport. Fast delivery of materials.
Suppliers	Providing materials	High level service, on time delivery	Willing to help contactors with just-in-time deliveries and bundling to increase load factor of transport	Take care of material transport and bundle different orders to increase load factor. In case of an establishment at the edge of city function as a hub.
Municipalities	Environmental protection and welfare citizens	Good accessibility, safety for on and near construction site, limited environmental damage	Pollution in urban areas too high, accessibility deteriorated by construction logistics	Set sharp regulations to achieve goals to activate stakeholders of interest. Subsidies to indirect support logistics solutions to decrease transport movements is focused on helping larger contractors with as goal to also improve the subcontractors' logistics efficiency.
Transporters	Shipping of goods	High level service, deliveries just-in-time	Take care of material transport and bundle different orders to increase load factor.	Help the contractors to meet the climate accord regulations by facilitating a hub and invest in zero emission transport.
Clients	Owner of building	Certainty of building finished on time, no unwanted costs	Costs and time of construction logistics should be minimized and not interested in green concerns	Renovation projects require temporary ejectment of residents. Construction project time's reduction leads to lower costs to compensate residents. That cost reduction can be realized if logistics solutions reduce construction time.
Local residents	Quality of life	Good accessibility in city, clean air, limited noise	Annoyed by pollution of heavy vehicles and the large number of transports and road disruptions	Fewer transport movements and more ZE vehicles to improve air quality and decrease nuisance.

Step 5: Analyze interdependencies

Previously in step 3 the formal relations have been determined. In this step, the goal is to determine the dependency relations between stakeholders and thereby the informal relations. Stakeholders' resources that explain the relationships. Resources can be distinguished categories such as knowledge, manpower or position in network (Kok, 1981).

Table 33: Stakeholders' resources

Stakeholder	Resources

Main contractors	The main contractor is the decision maker about the logistics design. They are responsible for all actions that are taken at the construction site. SME contractors do not have the manpower to execute all activities in a construction project and therefore outsource disciplines. Can pick up materials themselves.
Subcontractors	Provide the manpower and expertise that the main contractor does not have. May possess heavy equipment depending on the disciple they are working in.
Suppliers	Position in network is supplier of materials and have a variety of contractors buying from them. Possibly located at city's edge.
Municipalities	Authority regarding ZE zones and regulations about delivery times. Financial resource of subsidies to encourage lower emissions.
Transporters	Experts on transport of materials and route planning. Large vehicle fleet to support others that have a lack of vehicles. Owners of vertical transport vehicles. Space available for warehousing possible at the city's edge.
Clients	Give information to the main contractor through an intermediate architect that hands over the design of the project. The project's total construction costs are paid by the client.
Local residents	Power to vote to political parties that represent their best interest. Legitimacy that exposure to emissions is minimized.

Resource dependency of a stakeholder towards another stakeholder depends on the importance of the resources and the degree to which the resources can be replaced by other resources. Furthermore, blocking power also contributes on the resource dependency as stakeholders might hinder the operations of the problem owners, that are the contractors. Solutions to the problem situation results in that there are no stakeholders with blocking power. All stakeholders benefit from more sustainable construction logistics. The dilemma lies in the blocking power by the problem holder themselves.

Economic resources are based on three fundamental types which are natural, human and capital. Natural resources are depletable resources such as air, water, oil, gas and iron. These resources are indirectly the materials needed for construction. Contractors do not have the resources and expertise to produce the construction materials themselves and are therefore dependent on the suppliers. Another aspect is the use of land as storage. Urban area construction involves minimal storage space, making storage at a separate location a resource they can depend on. Human resources are all work provided by human input. Most of the work can be done by the main and subcontractors themselves. Other stakeholders can also offer labor necessary. However, this replaceability does not give them the high power. Capital resources are the investment in capital goods that can be used to manufacture other goods and services in the future. Fixed capital includes the new technologies, heavy equipment and vehicle fleet. This is what differentiates suppliers and transporters from contractors. Small contractors do not have the financial means to own expensive vehicles and cranes and are therefore dependent on third parties. Money is not a capital resource because it is considered a productive resource.

Political resources are defined by Dahl (2006) that has value to achieve political ends such as money, reputation, legal status, social capital and knowledge. The legal status is set apart in this resource dependency analysis as legal resources. The formal relations in step 3 show the legal resources all stakeholders have on each other and are used here. Cognitive resources are leadership capabilities. The effectiveness of a leadership is when individuals respond to problems, challenges and choices in an active way where they can recall needed information. A good leader has resources such as intelligence, skills and experience. It is closely related to the human resource but that resource is more about the human effort than the expertise of its effort.

Table 34: Stakeholders' interest and power

Stakeholder	Interest	Power						
		Economic			Political	Legal	Cognitive	Average
		Natural	Human	Capital				
Main contractors	High	Medium	High	Medium	Medium	High	High	High
Subcontractors	Medium	Medium	High	Medium	Medium	Medium	Medium	Medium/high
Suppliers	High	High	Medium	High	Low	Medium	High	Medium/high

Transporters	High	Low	Medium	High	Low	Low	High	Medium
Municipalities	Medium	Medium	Low	Low	High	High	Low	Medium
Clients	Low	Medium	Low	Medium	Low	Low	Low	Low
Local residents	Medium	Low	Low	Low	Medium	Medium	Low	Low

Table 34 shows the degree of interest and power divided into separate categories in a range of low-medium-high. The analysis on stakeholders' dependencies is summarized in the power-interest matrix (Figure 33) with interest on the x-axis and power on the y-axis. This matrix has a stakeholder category for each quadrant. It should be noted that the positions are based on the conducted interviews and literature review. The stakeholders' interest and power from Table 34 have been used to place them as correctly as possible.

High interest / high power (key players)

These are the key players that need to be worked closely with and ensure that they are consulted, collaborated and engaged completely. The main contractors have the maximum power and interest because they are the problem owner and their choices on how to manage the logistics are decisive. The subcontractors are positioned on the border of context setters and key players. 83.7% of employees in the construction sector are freelancers (as shown in Figure 8) and therefore most of the subcontractors are freelancers. Freelancers have a short-term planning and are not thinking about measures to protect themselves for the coming ZE zones. Main contractors plan short term and long term and do address this problem already and are therefore considered to have to most power and interest in the problem situation. The suppliers' (wholesalers and producers) and transporters' customers are the contractors. Their business model is dependent on the construction logistics problem situation.

Low interest / high power (context setters)

The municipalities' quadrant is the context setters. Municipalities represent the local residents and consider the local residents' problems as theirs. Because of their high power with regulations and permits they influence the actions to be made by the key players. The municipalities need to be kept satisfied without going into details on a daily basis. The formal relations chart (Figure 32) shows that by setting the ZE zones and issue construction permits they have a considerable amount of power but they do not have economic resources to support the key players.

High interest / low power (subjects)

The subjects are those who are interested in the project outcomes and should be communicated with regularly. Nonetheless is their power limited. There are no stakeholders in this quadrant.

Low interest / low power (crowd)

The low interest and low power quadrant is the crowd which are the clients and local residents. The crowd needs to be taken an eye on and their interest level needs to be monitored. The clients and local residents need to be engaged with generic communication methods that need limited effort with less detail and frequency (Gudavajhala, 2017). Local residents are close to the subject quadrant because the positive effects of ZE zones will be applied to them. Fewer transport movements increase the accessibility, livability and safety whereas less emissions increase their health and positive attitude towards the city.

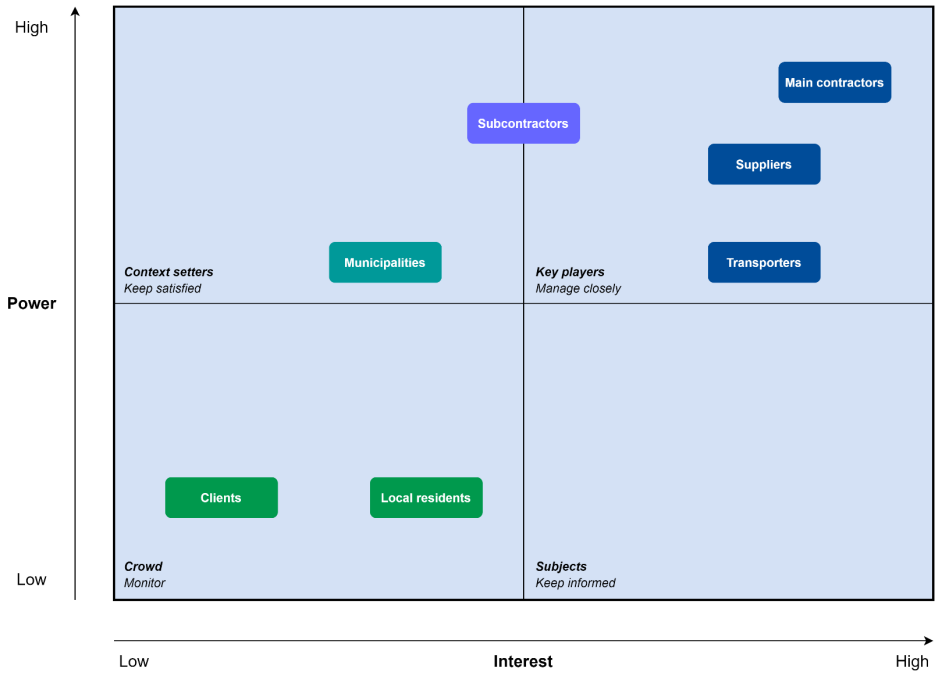

Figure 33: Power-interest matrix

There are several conclusions that can be drawn from Figure 33. The specific conclusions of stakeholders are described above grouped on key players, context setters, subjects and crowd. The first conclusion is for who the actions (monitor, keep satisfied, keep informed, manage closely) are applied. These are described in Table 35 below.

Table 35: Necessary actions stakeholders must take based on power-interest matrix

Stakeholder (subject)	Stakeholder (object)	Type of action	Action
Main contractors Suppliers Transporters	Main contractors Suppliers Transporters Subcontractors	Manage closely	The long term relationships that these stakeholders have with each other must be maintained. If a stakeholder has a new idea about how to set up a logistics solutions, the other stakeholders must listen and think along with that stakeholder.
Main contractors	Subcontractors	Keep satisfied	The main contractors must keep their subcontractors satisfied to not lose them.
Main contractors Subcontractors Suppliers Transporters	Municipalities	Keep satisfied	The municipalities have set regulations that the stakeholders (subject) must adhere to. These regulations, the upcoming ZE zones, are the foundation of this thesis project. This will result in that stakeholders are going to change themselves in how they operate because they are a highly traditional sector.
Municipalities Main contractors	Local residents	Monitor	Local residents should not experience any nuisance and must be monitored if this is the case.
Main contractors	Clients	Monitor	The main contractor must monitor the clients because they are paying the main contractor.

The actions that apply on subcontractors are the more interesting that will lead to the second conclusion. Subcontractors are on the edge of key player and context setter even though they are the problem owner together with the main contractors. Therefore, there are two actions that apply on them: keep satisfied and manage closely. An interviewed main contractor mentioned the problem that they are able to oblige them to adopt logistics solutions. This corresponds with the action of manage closely. However, the main contractor is afraid of losing their subcontractor to another main contractor if there are too many rules that the subcontractor should adhere to. That is why the position on the edge with context setter is interesting. The main contractor want to keep their subcontractors satisfied.

The third conclusion is the position of municipalities which is that they are a context setter and not a key player. Reducing emissions and increasing livability and accessibility is the municipalities' goal and not of anybody else. Their interest is limited because the ZE zone regulation has already been made and their intention is that the key players will find solutions themselves. The key players are still not acting enough to do something with the problem situation and are waiting for others to make a move. Municipalities' interest should increase to initiate the key players. Their opinion is that the market forces will provide the necessary solutions. However, Figure 13 already shows that fossil fuel delivery vans are still ordered as usual. The subcontractors even have their delivery van longer than main contractors because their organization is smaller as shown in Figure 14. This implies that already a large share of the subcontractors has a delivery van that is not depreciated in 2025 thereafter they are banned to enter urban areas with their delivery van. The longer everybody waits, the larger that share of contractors will become.

Step 6: Confront initial problem formulation with findings

Subcontractors in general do not care about sustainability and therefore are not willing to pay for sustainable alternatives if costs increase. Only when the legislations are introduced that it will be forbidden to drive with emission emitting vehicles from 2025 and trucks from 2030 they are confronted with the problem situation. At this moment, their interest in the problem situation is too low. Contractors, and thus subcontractors and main contractors, are both the problem owner. They need to have sustainable alternatives in 2025 to transport with ZE in urban areas. Subcontractors only care about performing their job and main contractors want that their subcontractors deliver the quality that they desire within the time they have. The subcontractors purchase their own materials and decide how they arrive at the construction site. Even though the main contractors' cognitive resources are high, they are afraid to oblige their subcontractors to switch to sustainable logistics solutions.

The subcontractors' interest is medium and not high as shown in Figure 33. They are on the edge of being a context setter or key player. Key is to incentivize the subcontractors in such a way that they are willing to adapt themselves. Main contractors are more organized and already do think about possible solutions to confront the prospective problem situation. The other key players, suppliers and transporters, are willing to help because it is one of their main objectives to deliver high service.

This stakeholder analysis shows that the problem does not need to be addressed only on a technical level (how to apply logistics solutions) but also on a human level (the role of people in transport). The people who are responsible for the transport movements still need to be encouraged to apply a logistics solution if a logistics solution can decrease transport movements significantly without too many additional costs.

APPENDIX IX. STAKEHOLDERS' PERCEPTIONS ON LOGISTICS SOLUTIONS

The perceptions on logistics solutions of the stakeholders that resulted out of the interviews are described below. The groups of stakeholders are contractors, wholesalers and transporters.

Contractors

SME contractors usually do not have enough personnel and expertise to execute the entire construction project. This depends on the type and size of the project. The number of employees, type of construction work and annual revenue of the interviewed SME contractors is shown in Table 2 in Appendix IV. Maintenance is something that main contractors can execute with their own personnel. Renovation, transformation and new construction are larger projects and require subcontractors. An interviewed contractor has for every discipline a selection of three or four subcontractors that they hire. The disciplines are roofers, painters, plasterers, electricians and tilers. Another interviewed contractor use their own professionals for activities such as concrete work and carpentry. This means that each contractor has a different list of operations. The logistics solutions (see Table 21 in Appendix II) identified in prior research were discussed on whether they would be applicable to small-scale construction projects. Not all respondents were familiar with certain logistics solutions because it is dependent on the list of operations that they perform.

CCC

At this moment, CCC's are not used as a tool to improve sustainability in urban areas for small-scale projects but rather because of the complexity of the project. A contractor mentions that working with CCCs in the shell construction phase and in façade installations is inefficient because of the extra intermediate storage. That contractor's activities are mostly new construction in urban areas which makes the use of a CCC more appropriate. Another contractors is not using a CCC but a waiting area for deliveries as a hub. That contractor is planning to use a transporter's establishment as a hub for a construction project. This is the first time they will make use of a hub thus they are unexperienced with a CCC as a logistics solution.

Prefab

Prefab is a logistics solutions that is not something of recent years. It has always been there and in the past it was the same as in the present. However, there is a trend that more and more is prefabricated. Branch organization of suppliers Hibin (2019) conducted a research among mostly suppliers and some others such as contractors and interest groups. The opinion of the respondents was that in new construction the share of prefab will increase and in 2025 half will be built from prefab. The respondents could choose between three answers on the question " What is the percentage of prefab in renovation according to you in 2025?". The answers were low (10-30%), middle (40-60%) or high (70-90%). The majority of the respondents answered that the share of prefab in renovation will be low in 2025 (see Figure 34). However, the larger the construction becomes, the more parts can be standardized and be prefabricated. Therefore, prefab for medium-sized construction projects becomes a feasible logistics solution. Another aspect of prefab is 3D-printing. Research about 3D-printing in construction is taking place but the use of 3D-printing for a canal house is undoable according to an interviewed contractor. Hence, urban area 3D-printing is unrealistic.

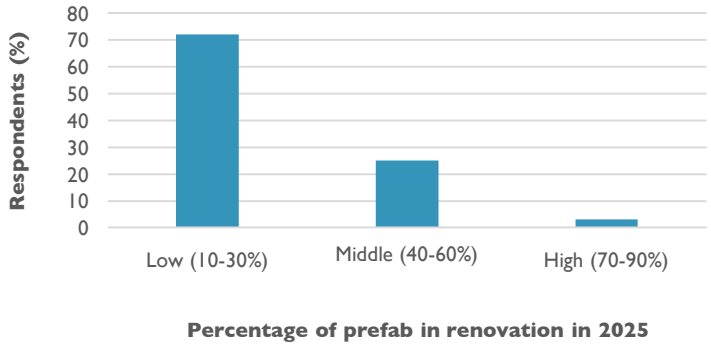

Figure 34: Respondents answer to the question "What is the percentage of prefab in renovation according to you in 2025?" (HIBIN, 2019)

Runners

Runners are useful in case of limited storage space on location or stacked buildings such as apartments. Wholesalers and their transporters offer this as a service but it can also be performed by the contractors' employees themselves that they are dedicated to that role during a day. A contractor experienced that the hours needed to move the materials to the right location, especially in stacked buildings, is tremendous. Two wholesalers are assisting the contractor to make use of runners by creating a hub at their establishment and transport all materials once and runners will move it to the specific room. Transporters, specifically moving companies, are making more use of this logistics solution. They have different collective labor agreements that allows them to supply in the night. Outside construction time delivery is a coherent logistics solution that optimizes the distribution. The contractors are obliged to their working day which is from 07.00 until 19.00. Supply outside their working day optimizes the use of the construction site.

Building tickets

A contractor determined that a highly efficient logistics solution in the shell construction phase is the use of building tickets to create just-in-time deliveries. With this building tickets they communicate to a different party the required materials and in which time slot the delivery can take place. The contractor works with a waiting area for deliveries outside the city together with this building tickets system.

Waiting area for deliveries

A contractor is planning a project in Rotterdam where the construction site is too small for normal logistics operations that they are thinking in a different way. All materials need to be delivered just-in-time and therefore they will use a hub. The hub is not an organized CCC but rather a place where they can park their vehicles for free. Waiting area for deliveries is the actual term for this hub (see Table 21 in Appendix II for explanation). It is not owned by the contractor but used by them to transport the materials on the desired time to the construction site. A requirement is that the hub needs to be close enough to the site that the time schedule can be achieved.

Smart return

Waste is often all collected in a waste container without any separation. They choose to let the waste sorting separate the types of waste. A contractor prefers to work with containers because the available space is limited to separate waste and there is a chaos of subcontractors that end up with waste and they all dump it in the waste container. The chaos of waste makes it difficult to realize smart return.

Transport over water

Contractors know about the organizations that use transport over water and approve this logistics solution. However, there are doubts in how useful it is for their small-scale projects. The first problem is how to move the materials from the water to land and afterward construction site. The movement from water to land is an additional action. The second problem is that a boat cannot dock everywhere which oblige the boat to go back and forth. These two problems cause that it is more expensive. A contractor used water transport once and made a mistake in calculated costs and therefore have negative experience with this logistics solution.

Carpooling

Carpooling can be organized by a main contractor. A contractor is positive about the use of carpooling. It is dependent on how the arrangements are set. If there is many space available for the personnel to park their vehicle than will they all drive on their own. The main contractor needs to organize his personnel transport if there is no space available. People automatically handle this transport in an efficient way if these arrangements are communicated in a way what the possibilities for personnel transport are. Another contractor has had a delivery van system where one driver picked up multiple persons. However, at this moment their personnel are living more away from each other than before. On average two people are in the truck together while in the past the truck was filled with seven people. Their drivers are not willing to fill up their delivery van because the travel time will become too large. Carpooling is only favorable if there are living a large number of personnel close to each other or on the road to the construction site. The use of a location on the city's edge is a possible solution. Subcontractors, and even main contractors' own personnel, prefer to use their own delivery van for two reasons. They do not like to walk and they always want to have their own equipment.

Material container

The interview of a contractor led to conclusions about the feasibility of a material container for small construction projects. The use of a material container is used rarely in urban areas and deliveries take place just-in-time. The storage areas at the site is minimal. Contractors need to have crates, equipment, lost dust baffles, eating space and materials at the site. A material container could help but is expensive in urban areas because of parking costs. The interviewed contractors do have limited experience with this solution.

BIM

The difference between BIM and normal designs of architects is that BIM is 3D and the normal designs 2D that most of the architects and construction management agencies still use. The use of BIM is intended for new construction. The process and materials alignment is a requirement in a 3D model for the subcontractors and therefore not yet possible in renovation projects.

Wholesalers

The service provided by wholesalers is one of the key activities in which they want to distinguish themselves from others. The probability that contractors switch from supplier is small because the contractors are traditional meaning that if the service provided by a supplier, it is unlikely that they will switch from supplier. Wholesalers usually do not own vehicles. They have long term transporters where they collaborate with. These transport companies own the vehicles. However, some trucks are dedicated to the wholesaler. The wholesaler's logo is on that truck and the driver only drives for them. A wholesaler explained this situation to those drivers as "You are employed by us. The only thing is

that somebody else pays you.". If the wholesaler needs more vehicles or specific vehicles, such as a truck with a forklift truck or a loader crane truck, than the transporter will provide those vehicles to the wholesaler. The wholesaler's logo and the driver are of high importance to wholesalers. The wholesalers are not keen to let a competitive wholesaler deliver their transport to the customers. A white label concept to combine their materials is a feasible logistics solution. The white label concept can operate by a CCC or by a transporter who organizes the logistics.

CCC

The respondents were asked on their experience with CCCs. Two wholesalers were positive on this logistics solution. One of them is developing the use of a CCC for 4 to 5 years and uses permanent partners. The methodology is excellent. However, the question is whether the customer has thought about making use of a CCC. Additional costs, due to intermediate storage, are associated thus the necessity must be present to provide added value. People are not moving without that necessity. The other of those two wholesalers confirms that necessity because they only use a CCC if the logistics is a challenge. The third wholesaler has its doubts about CCCs. They have never used a CCC before. The request must come from the customer. The reason why there has not been a request are the additional costs. Furthermore, that wholesaler does not believe that the use of their establishment as a hub is possible if the establishment is not close to the city.

Runners

Wholesalers offer runners as an additional service where the client needs to pay for. The costs of such a runner is on an hourly rate. People in construction are scarce. Those people prefer to focus on their construction operations instead of moving the materials to the location. Two advantages of runners are that their hourly rate is lower than the contractors' hourly rate and that it reduces the labor intensity. However, the additional costs are a barrier for most contractors. Their personnel or subcontractors are task-oriented meaning that the amount of daily work will not increase if a runner is used. There is a difference in the use of runners between micro, small and medium projects. Runners are used rarely in micro projects. It depends on the type of customer if runners are used for small and medium projects. Maintenance projects have housing corporations as client. The housing corporations are owner of multiple residences that need maintenance at the same time. Runners in such projects are useful.

Smart return

Wholesalers use smart return as a logistics solution. The materials that go return are wrongly delivered products or waste. Wrongly delivered materials is something that wholesalers are willing to take back and is a rising phenomenon in recent years. The return flow of waste is organized differently. A wholesaler only takes waste return on request. Another wholesaler has several services for return flows: the use of BouwBewust boxes, bigbags, Keukenbox (English: Kitchenbox) and roller cages are services they are working on. This wholesaler mentions that arrangements should be made about supply and return logistics. The third wholesaler uses the same method as that of BouwBewust boxes. Materials are delivered in containers, the containers are filled with waste and they bring it back. Permits are required to block the street. Those permits are paid for and the combination of material supply and waste return reduces transport movements and permits to block the street.

Bundling of materials

The bundling of materials with other suppliers is a perfect solution to maximize the vehicles' load factor. The wholesalers are restrained for this solution. The company's logo on the side of the vehicle are of

interest for them. Transport is one of the wholesalers' tools in their business model. A wholesaler identifies that bundling of materials makes a lot sense from a logistics point of view. However, it affects the competitive position and the revenue model. One interviewed wholesaler has a national integrated logistics network, something smaller suppliers do not have. As a result, smaller suppliers benefit more from bundling of materials. Another wholesaler was not ready for a long time to bundle materials and are now in the phase that it is possible. Data makes bundling complex. Specifications on volume, length sizes and stackability are required. The wholesaler always use the example of a kitchen cupboard to explain stackability. A pallet of plaster cannot be placed on a kitchen cupboard. The stackability relates to logistics because it determines how the truck can be filled thus how it can be unloaded. Data of different suppliers must be universal that they can be merged together to design the truck's layout for a trip to deliver the materials.

Delivery/pick-up

The smaller the contractor, the more likely that he will pick up materials at the supplier's establishment. A wholesaler has several customer segments that included the contractor's size as a specification. The employee is not allowed to pick up materials if the contractor is larger because it is a waste of time. The wholesaler has reached its limit regarding pick-ups. Traffic jams occur in the morning at their establishment. Deliveries are promoted because the wholesaler can better structure those operations. Hence, their growth will take place in that area. Another wholesaler is composed out of two companies where the focus on customer segments differ. One of those two companies' customers are the freelancers and small contractors (approximately five employees) whereas the other company's customers are the SME contractors. This wholesaler hopes that the freelancers and small contractors pick up their materials. The third wholesaler's establishments are designed as pick-up locations because they also have pick-up customers and those customers will remain according to them. If a contractor is smart, he will have everything delivered. However, the customers determine their own planning. A freelancer is his own boss. It does not matter to those freelancers if they work eight or ten hours a day. People only need to be organized as efficient as possible in case that a contractor has employees.

Rush orders

Rush orders are a service provided by wholesalers that is used more regularly. A wholesaler is integrating rush orders conceptually because they sensed that competitors were offering this as a service. More contact with the customers is another opportunity to increase customer loyalty. The second wholesaler also works with rush orders. It is only possible if the ordered materials are available in the establishment nearby. This wholesaler operates with a national distribution center (DC). This wholesaler cannot deliver the materials with a rush order if an order contains a product that is only present in their national DC. The third wholesaler has box trucks at several of their establishments that are used for rush orders. The products delivered are usually small and for completion construction. High importance rush orders such as a delivery within two hours is also one of this wholesaler's services. This can only be seen as a service and not as a revenue model.

Transporters

The two interviewed transporters have different type of clients and are therefore different types of transporters. One transporter's clients are contractors, wholesalers and freelancers. Occasionally, a private individual is their client as most of the private construction works are executed by contractors. Producers are rarely their client. Their focus is for that reason on completion construction. The other transporter is specialized in transport of prefab concrete shell construction, glass, wood and sheet material. Their main activity is transport of hollow core slab floors, a specific type of prefab floor.

Application of permits is a service that is performed by the transporters. Their focus is on shell construction.

The completion construction transporter is convinced that hubs are the answer to urban area logistics for the future. Not everyone will enter the cities in the future to deliver their materials. Hubs will function as an intermediary station. This is the optimal logistics solutions because of two reasons. The first is to reduce the number of transport movements and the second is the introduced environmental legislation. The respondent tried to implement a hub with Port of Amsterdam six years ago. Municipality Amsterdam understood the intentions of this transporter. However, at that time municipality Amsterdam was unable to cooperate with that initiative because providing a location was not possible. The interviewed municipality of this thesis project confirms the problem of scarce land. They made an inventory on available and affordable land appropriate for a hub and concluded that all land in and around Rotterdam have an owner or destination. Another aspect addressed by this transporter is that it would be beneficial to operate a small number of hubs by entrepreneurs to prevent sprawl and to maximize the trucks' load factor. If many entrepreneurs operate a hub, the efficiency will decrease. The hubs referred to in this case are CCCs which are a specific type of hub.

The transporter is in conversation with vehicle manufacturers Volvo and DAF about full electric trucks. However, the electric trucks' purchase is a complicated process and they still do not have electric trucks. They assume that in one or two years they will have their first electric transport movements. In the meantime, they developed an electric traction for a loader crane truck. This adjusted truck drives on biofuel instead on fossil based fuel that results in a reduction of 89% of NO_x emissions. The loader crane operates on electricity that has an additional advantage next to emission reduction which is noise reduction. The noise drops below 70 dB (Decibel) and usually when a truck's engine is running stationary to control the loader crane the truck produces 80 dB. For comparison, a normal conversation has a loudness of 60 dB and a vacuum cleaner 70 dB. A small difference in dB is a large difference in noise perception because dB is not a unit but a ratio on logarithmic scale. Moreover, the noise of produced by trucks' engines is analyzed by Van der Maart and De Beer (2019) that shows a significant difference between a diesel truck and an electric truck at different speeds of 20, 25 and 30 km/h (see Figure 35). The transporter is positive on the regulations and even hopes on stricter conditions such that these developments will be fundamental.

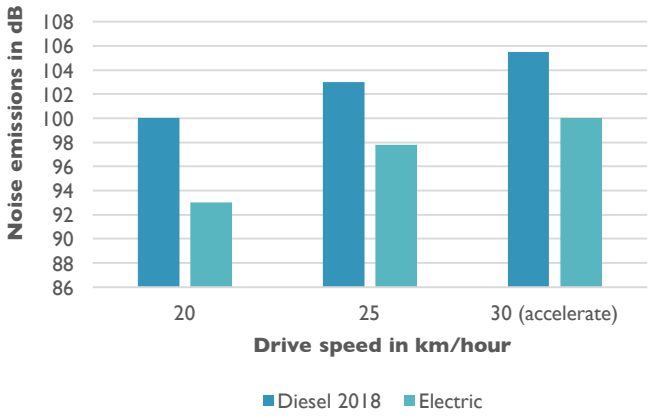

Figure 35: Comparison of vehicle engine's noise between diesel and electric trucks (Van der Maart & De Beer, 2019)

The shell construction transporter's transport is different than the other transporter. Their materials are made-to-order, specific to the building under construction. The trucks' hydraulic cranes unload

two-thirds of the materials on location. The remaining one-third are the materials too large for the trucks' cranes. In that situation, the transporter is dependent on the contractor's tower crane. Their trucks transport approximately 30 metric ton thus their load factor is already maximized. The respondent indicates that the use of a hub as an intermediary station is ineffective for shell construction's prefab parts. Logistics solutions are too difficult for the transport segment in which the transporter is active. Electric trucks do not fit in their business model. A truck drives between 80,000 and 100,000 km per year and are supposed to drive 1,000,000 km in a truck's lifetime. This makes a depreciation period of 10 years. Trucks will be banned from 2030 in urban area meaning that long term capital investment is already important at this moment. Therefore, logistics solutions for heavy transport for these types of transport movement is difficult to implement. 7.2.7 Difficult ZE implementation explain where exemptions should be made if logistics solutions are infeasible.