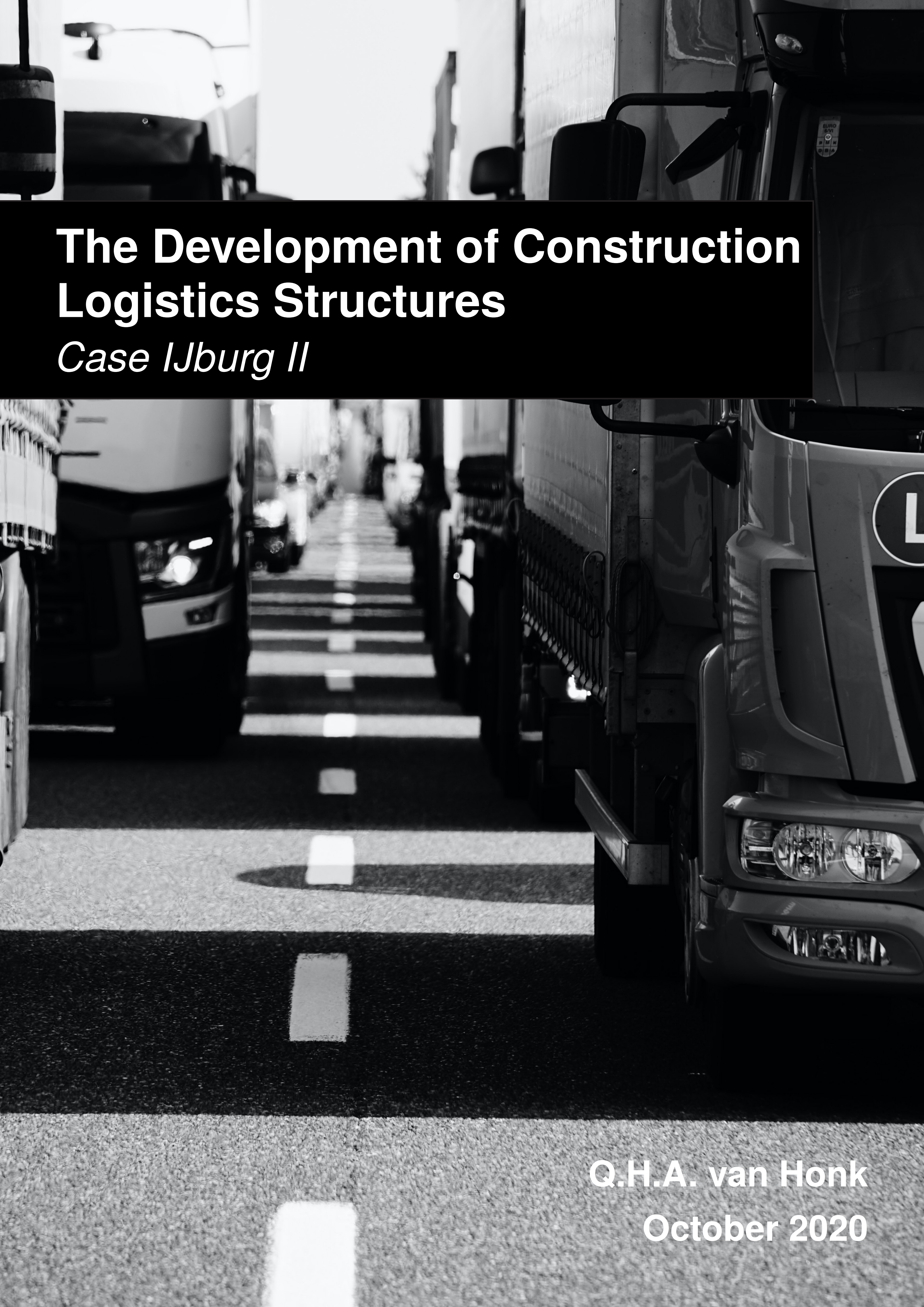

The Development of Construction Logistics Structures

Case IJburg II

Q.H.A. van Honk

October 2020

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By

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To obtain the degree of Master in Science in Transport, Infrastructure and Logistics at the Delft University of Technology.

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Preface

This thesis was written for the partial fulfillment of the Master Transport Infrastructure & Logistics at the Delft University of Technology. The graduation project about construction logistics for the development project IJburg II was a collaboration between the Delft University of Technology and the Ingenieursbureau van de Gemeente Amsterdam. In this subject my two study backgrounds, the Bachelor Civil Engineering and the Master Transport Infrastructure & Logistics, came together well.

I would like to express my gratitude to the graduation committee who provided me with the necessary feedback during the thesis process. First of all, I would like to thank Lori Tavasszy, as chairman of the committee, for pointing me in the right direction during the several meetings. His critical view on construction logistics gave me different insights each time. Second, I would like to thank Marcel Ludema. In the first place, for providing me the contact with the Ingenieursbureau van de Gemeente Amsterdam. But also, for the intensive and personal guidance throughout my thesis. Marcel's expertise of construction logistics in Amsterdam has brought my thesis to a higher level. Lastly, I would like to thank Arjan van Binsbergen for the detailed and critical feedback on my work which helped me deepen my thesis. In addition, for helping me formulate my problem and narrative more properly.

Of course, I would also like to express my gratitude to the Ingenieursbureau van de Gemeente Amsterdam for giving me the opportunity to do my graduation research there. More specifically, I want to thank Janke Algra for her involved guidance from the Ingenieursbureau. Her enthusiasm for and vision on the project were of great help. Moreover, Janke has helped me with getting the right contacts within het Ingenieursbureau and provided me with all kinds of necessary information. In addition, a big thank you to Lianne, Frits and Matthé for the weekly meetings and all the other employees of het Ingenieursbureau van de Gemeente Amsterdam and Verkeer en Openbare Ruimte that helped me during my thesis. Furthermore, a special thanks to the supervisors and students of the 'Studentenuur'.

Next to that, I would like to thank my friends. In particular, my roommates and study friends for their interest and tips. Last but not least, a special thanks to Boaz, Lonneke, Theo and my parents for their interest, patience and support not only during this thesis phase but throughout my study period.

Quint van Honk
October 2020

Summary

At this moment, the Dutch housing market is struggling with a major shortage of houses (Capital Value and ABF Research, 2019). The housing shortage is a problem throughout the Netherlands, but the situation is particularly acute in large cities. This is due to the fact that more and more people are migrating to urban areas. The foregoing implies that new urban development projects are required in the upcoming years to overcome the housing shortage. Urban development does not only consist of residential and non-residential development but also includes the construction of infrastructure (in Dutch: Grond- Weg- & Waterbouw). However, infrastructural development is not included in this thesis. The new required construction activities lead to the generation of transport flows of construction materials, equipment and construction personnel.

Construction-related transport is the most polluting source of all freight transport in a city (Topsector Logistiek, 2018). Therefore, well-organised logistics is required to manage these transport flows. The term construction logistics is used for the management of construction-related flows. Thus, construction logistics involves the planning, organisation, coordination and control of the construction material flows from the extraction of raw materials to building site (Ying et al., 2014). Recycle or waste flows are also included (Lundesjö, 2015). At the moment, however, construction logistics leads to a number of problems: additional costs in the construction process, a poor quality of construction works, longer project times and negative impacts on the urban environment (Gustavsson and Gohary, 2012) (The Strategic Forum for Construction Logistics Group, 2005) (Sullivan et al., 2011) (Janné, 2018). A number of proven negative effects of construction logistics on the urban environment are the increase in congestion, the decrease of road safety and the higher amount of noise and air pollution (Macharis et al., 2016). This indicates that a change in the construction logistics structure is required to counteract the negative effects. Change is not only necessary from this point of view, but also because municipalities are imposing increasingly stringent requirements with regard to transport vehicles. The construction industry has so far been unable to change the construction logistics structure to address these problems. This is mainly caused by the low level of cooperation between the large number of stakeholders in construction logistics (Sullivan et al., 2011).

The problem of housing shortage also occurs in Amsterdam and has invoked numerous urban development projects. One of these urban development projects is IJburg II. The construction of IJburg II will increase the amount of construction-related transport to, in and from Amsterdam. The Municipality of Amsterdam is one of the municipalities that imposed more stringent requirements with regard to transport vehicles and has high ambitions to reduce the negative effects on the urban environment in particular on air quality. The Municipality of Amsterdam expects that the construction industry will not come up with a solution of its own and thinks that drawing up stricter strategies for construction logistics alone will not lead to the achievement of the new ambitions related to construction logistics. In addition, the Municipality of Amsterdam wants to be assured of smooth construction logistics in the future, even under the stricter strategies. That is why, the Municipality of Amsterdam itself wants to think about new construction logistics structures. However, the Municipality does not know how this new structure should like because to date, these construction logistics structures are not identified. Therefore, this thesis has the following thesis project objective:

> *To design conceptual construction logistics structures for residential and non-residential development on IJburg II that meet the new ambitions of the Municipality of Amsterdam related to construction logistics and construction activities.*

As can be inferred from the thesis project objective, the thesis focused on the design of new construction logistics structures for IJburg II for the supply and disposal of construction materials for residential and non-residential development. To come up with designs of a construction logistics structure for IJburg II, a number of steps were taken. First, the project IJburg II was analysed on construction phases and construction flows by means of a case study. The case study revealed a number of relevant aspects of the project such as the building characteristics, the construction sequence, the to be used construction materials and techniques, and the generated construction material flows. Furthermore, the ambitions and strategies of the Municipality of Amsterdam related to construction logistics and construction activities for IJburg II were identified by means of document analyses.

The gathered information in the case study was used to define the design requirements and preconditions. These requirements and preconditions were thus drafted from the point of view of the Municipality of Amsterdam. The requirements were divided in need to haves (constraints) and nice to haves (objectives). Subsequently, designs for subsystems of the construction logistics structure were generated in the design synthesis based on the system requirements and preconditions. The new subsystems designs were generated with applicable construction logistics centres and new types of transport derived from literature. This led to several new designs for subsystems of the construction logistics structure. Out of these subsystem designs, three new logistics structures for IJburg II were developed.

The three developed construction logistics structures were tested against the earlier drafted requirements both qualitatively and quantitatively. The requirements were tested quantitatively by means of a newly developed calculation model in Microsoft Excel. This model calculates the vehicle movements and the CO_2-, PM_x- and NO_x-emissions for construction logistics per design. The designs that comply to the drafted nice to haves were subsequently evaluated based on stakeholders' perceptions of six stakeholder groups. The stakeholders' perceptions, needs and influence were first identified through a stakeholder analysis.

In this thesis, three new construction logistics structures for IJburg II that could potentially meet the new ambitions of the Municipality of Amsterdam related to construction activities and construction logistics were designed. The design verification showed that two of the three new designs comply to the need to haves (constraints). This means that the thesis project objective was achieved. However, one of the designs, design 2, did not comply to the need to haves. This because the results of the calculation model showed that design 2 did not realize the required 25%-reduction of CO_2-emissions due to construction logistics movements. Based on the scores of the nice to haves, construction logistics structure design 1 seemed the most favourable design out of the two remaining designs due to the inclusion of waterborne transport and the higher decrease of road congestion by construction logistics.

The results of the calculation model indicated that all the three new construction logistics structures establish a high reduction in CO_2-, PM_x- and NO_x-emissions. In addition, all the designs significantly reduce the number of vehicle movements towards IJburg II. However, the vehicle movements on IJburg II (last-mile deliveries) remain unchanged or even slightly increase in the new designs what can be explained by the deployment of light electric vehicles. Since IJburg II is not a one of a kind project in the Netherlands, the outcomes of this study can be generalized. This implies that other similar urban development projects can achieve significant reductions of CO_2-, PM_x- and NO_x-emissions by implementing new logistics structures. The same applies for the conclusions about vehicle movements towards construction sites and about the last-mile deliveries.

Based on the evaluation of the design on the stakeholders' perceptions, the first steps towards an implementation plan for design 1 were made, as this design scored best on the nice to haves. The plan states that the Municipality of Amsterdam should specifically engage stakeholders for establishing the logistics structure. This targeted approach is effective because stakeholders only have issues with changes in the construction logistics structure that impact their own interests. However, before a new structure can be implemented, the design should be evaluated on more criteria such as costs, efficiency, safety and required land for logistics centres. This is necessary because this report focused mainly on the (environmental) benefits of the structure and not on the costs. Furthermore, it would be useful to do more research to construction logistics structures for infrastructural development in urban development projects, as this was not included. This extra research will increase the chances of a successful implementation. Two recommended directions for further research are thus to study the costs of new logistics structures and to design construction logistics structures for infrastructural development.

Due to time limitations, this study only developed and examined three construction logistics structures. However, many more logistics structure designs for IJburg II can be made by combining designs of subsystems which were drafted in this thesis. The report states two structures that comply to the new requirements but this does not automatically mean that these are the best and only solutions. Therefore, this report can be used as a tool for the Municipality of Amsterdam and other municipalities, who encounter the same problems in similar construction projects, to develop new structures. A recommendation for the Municipality of Amsterdam is thus to design and examine more construction logistics structures. In addition, it would be good for the Municipality to review all ambitions and strategies related to construction logistics and construction activities again to evaluate whether they actually match the goals of the Municipality.

Table of Content

List of Figures

List of Tables

1 Introduction

1.1 Background

1.1.1 Residential and non-residential development

Currently, the Dutch housing market is struggling with major housing shortages. In 2022, the housing shortage is expected to rise to 380.000 houses (Capital Value and ABF Research, 2019). Therefore, the production of houses needs to increase to counter the housing shortage. Estimates show that 845.000 new houses are necessary in ten years to meet the population growth in the Netherlands and to overcome the housing shortage (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2020). This means more than 80.000 houses per year (Hulsman and de Voogt, 2020). These numbers indicate that in the coming years many houses will be constructed, as new build houses will have to make up for most of the housing shortage (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2020). The development of urban areas does not only require residential development but also non-residential development and infrastructural development (in dutch: Grond, Weg & Water). However, this thesis does not cover the construction of infrastructure. The construction activities for residential and non-residential development can be roughly divided in four construction phases. The four construction phases are depicted in figure 1 and are explained below:

1. **The construction site preparation:** the construction phase of machining the ground level to enable construction activities. This phase could include construction activities such as excavating, heightening and pre-loading the ground.

2. **The substructure construction:** the phase in which the foundation will be constructed for the new structures.

3. **The shell construction:** the construction of the casco. At the end of this stage, the framework is wind- and waterproof.

4. **The final construction:** the construction phase in which the building is to be completed. This stage is characterized by mostly indoor construction activities. After the final construction phase, the structure is ready for delivery.

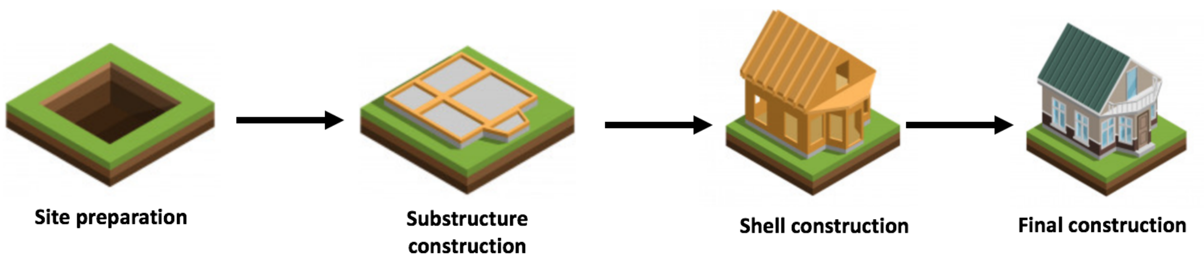

Figure 1: The four construction phases residential development

1.1.2 Construction material flows

The trend in residential development is that the construction activities are shifting from residential development projects outside the city (greenfield) to development projects in urban areas (brownfield). In addition, already 50% of the construction activities take place in urban areas (Vrijhoef, 2018). This percentage is expected to rise because more and more people are migrating to cities which only increases the need of new build houses in urban areas. The construction activities in the cities generate transport flows to and from the construction sites for the necessary supply and removal of construction materials, equipment and construction personnel. Recent research showed that 30 % of the total transported freight tonnage in cities is caused by transport of construction materials (Guerlain et al., 2019). This makes construction-related transport the most polluting source of all freight transport in a city (Topsector Logistiek, 2018). Construction-related transport consists for a large proportion out of transport of construction materials. However, the transport movements of construction personnel can also be of significant size (Rinsma et al., 2015). This thesis focuses on the transport of construction materials, as these flows have a high impact on the urban environment. Research of Klerks et al. (2012) described six generic construction material flows for construction projects. The main characteristics of these six flows and how these are currently being transported are described below:

1. **Large time-critical full-truckload flows:** these are 'thick' full-truckload flows of construction materials with a time-critical element directly delivered to the construction site. However, the return trip is empty transport. An example of such a flow is ready-mixed concrete. Ready-mixed concrete is time-critical because concrete starts to cure after some time, even in a concrete truck. This type of flows cannot be bundled due to the time-critical element. Transport takes place form supplier to construction site

2. **Large non time-critical full-truckload flows:** these are also 'thick' full-truckload flows directly delivered to the construction site. Again, the return trip is empty transport. The flows mostly comprise of materials used for the substructure and shell construction (ruwbouw) such as piles, sand, gravel, insulation material, sand-lime bricks, wood, iron and metal. Transport takes place from the supplier or wholesaler to the construction site in a heavy truck

3. **Non time-critical small less than truckload flows:** these are the smaller flows of construction materials. The load factor of the transport vehicle is less than truckload which means a low load factor. Transport vehicles used for this type of flow are heavy or light trucks. These flows mostly consist of construction materials delivered on pallets such as glass, paint, installation materials and plasterboards. This type of flows are mainly generated in the final construction phase and originate from multiple suppliers and wholesalers.

4. **Non time-critical packages:** these are the smallest flows of construction materials. These deliveries to the construction site are much smaller than the non time-critical less than truckload flows. These flows are often transported in light trucks or vans. The load factor of the transport vehicle is low. This flow type is mainly generated in the final construction phase and originates from multiple suppliers and wholesalers.

5. **Time-critical rush orders:** this is the time-critical flow for the smallest construction materials. Transport mostly takes place by light truck or van and the load factor is extremely low. These flows are frequently caused by flaws in the planning or miscommunication between supplier and customer. This flow mostly occurs in the final construction phase and can be sent from multiple suppliers and wholesalers. Delivery should take place within a day to avoid delays in the construction process.

6. **Reverse flows:** these are all the flows transported in opposite direction from the construction site. There is a large variety in flows in this category as it is used as a collection group for all reverse flows. The flows are always non time-critical but can be both full-truckload or less than full-truckload depending on the type of waste. Transport vehicles arrive empty at the construction site and the return trip is full-truckload. The reverse flows can consist

of all kinds of construction materials depending on the construction phase. The reverse flows during site preparation will be primarily sand, while the waste during the final construction phase mainly consists of plastic and cardboard. The reverse flows are transported in containers or bulk to a waste disposer in different sizes of transport vehicles.

1.1.3 Construction logistics

In order to manage the growing number of construction-related flows, well-organised logistics is required. Logistics is a widely spread and used term which refers to the management of supply chain in commerce and industry (Lundesjö, 2015). In 2013, The Council of Supply Chain Management Professionals (CSCMP) used the following definition of logistics:

> *Logistics management is that part of supply chain management that plans, implements, and controls the efficient, effective forward and reverse flow and storage of goods, services, and related information between the point of origin and the point of consumption in order to meet customers' requirements.*

The term construction logistics is used for logistics management in the construction industry. Construction logistics involves the planning, organisation, coordination and control of the construction material streams from the extraction of raw materials to building site (Ying et al., 2014). This also includes the recycle or waste flows (Lundesjö, 2015). The aim of construction logistics is to get the proper material, equipment and personnel at the right place and time, in the right quantity and quality with the right price (Quak et al., 2011). The most relevant aspects of construction logistics are whole supply logistics and on-site logistics (Jang et al., 2003) (Sobotka and Czarnigowska, 2005). Supply logistics comprises the provision of the construction materials and personnel necessary for construction activities (Serra and Oliveira, 2003). This logistics phase has to do with the planning and processing of construction materials and the transport to the construction site. On-site logistics comprises the coordination of information and material flows related to on-site construction activities (Serra and Oliveira, 2003). The two phases in construction logistics activities are depicted in figure 2. What also can be seen in this figure is that construction materials are delivered from different suppliers to the construction site. Decoupling and consolidation of these materials in the construction supply chain can take place by adding new nodes (de Vries and Ludema, 2012). This will change the construction logistics structure.

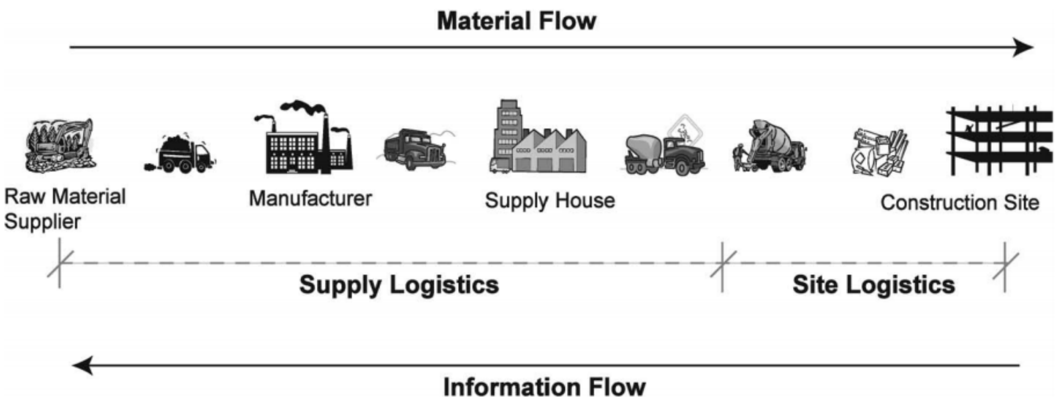

Figure 2: Construction logistics activities (Jang et al., 2003)

These days, however, construction logistics in cities causes a number of issues: additional costs in the construction process, a poor quality of construction works, longer project times and negative impacts on the urban environment (Gustavsson and Gohary, 2012) (The Strategic Forum for Construction Logistics Group, 2005) (Sullivan et al., 2011) (Janné, 2018). A number of proven negative effects of construction logistics on the urban environment are the increase in congestion, the decrease of road safety and the higher amount of noise and air pollution (Macharis et al., 2016). The construction industry is namely relatively slow with integrating dedicated logistics strategies and professionals in the daily operations which makes that the construction logistics structure has not changed significantly over the last decades (Sullivan et al., 2011). Hence, The Strategic Forum for Construction Logistics Group (2005) stated that a lot of opportunities to improve construction logistics are still unexploited. In addition, municipalities are imposing increasingly stringent requirements with regard to transport vehicles such as environmental zones and weight restrictions. Overall, it can be concluded that there are four obvious reasons to change the construction logistics structure:

1. To increase the efficiency and productivity of construction activities on site.
2. To improve the quality of construction logistics across an entire construction project.
3. To reduce the negative impacts on the urban environment.
4. To be able to continue to carry out construction logistics under stricter transport strategies of municipalities.

Municipalities acknowledge these issues in construction logistics and therefore want to change the construction logistics structure. In particular, to counter the negative effects on the urban environment and to continue to guarantee the supply and disposal of construction materials, as they are responsible for a safe, accessible, livable and healthy cities. At this moment, high ambitions are already formulated and new strategies are partly imposed regarding construction logistics in big cities such as London, Amsterdam and Stockholm which increases the need to change the logistics structure (Vrijhoef, 2018).

1.1.4 Construction logistics centre

In literature a wide variety of solutions have been proposed to improve the logistics problems in the construction industry. These construction logistics solutions are defined as means to ensure efficient construction material flows and to reduce negative impacts on the environment (Janné, 2018). An often proposed solution in literature is a centralized logistics centre (Seppänen and Peltokorpi, 2016). Other studies stress the urge for improving the delivery schedules and need for just-in-time deliveries. These improvements could be achieved by making use of digital or web-based systems for logistics or linking the logistics planning to Building Information Modeling (BIM) (Seppänen and Peltokorpi, 2016). Other suggested options are the engagement of third-party logistics providers (Ekeskär and Rudberg, 2016) (Quak et al., 2011), pre-assembly, production at the site (Sullivan et al., 2011) or standardization of the construction process. However, the applicability of a solution depends on the type of construction project (Quak et al., 2011).

The construction logistics centre is widely seen as an attractive solution to improve the construction logistics structure because it can support the logistics structure with multiple functions (Hamzeh et al., 2007). Literature explains the generic definition of a logistics centre in two ways (Meidute, 2005). First, as a part of the transportation infrastructure. The logistics centre is in this case a contact point of various transportation modes and vehicle types (with different capacity) where the distribution of freight flows is concentrated and performed. Material flows can for example be decoupled or consolidated in a logistics centre and be distributed from there. Thereby, it stimulates inter-modal transportation, serves a wide range of clients with value added services and presents new technological services (Meidute, 2005) (Hamzeh et al., 2007). Second, as a generator for business. In this sense, the logistics centre does not focuses mainly on the transportation activities but is used as a tool to improve the logistics services (Meidute, 2005). This thesis assumes the first meaning.

The configuration of a construction logistics centre can be adjusted in multiple ways enabling various functionalities in the construction logistics structure such as: storage, transport, distribution, consolidation, decoupling, assembly, production, and management of distribution network and vehicle routing Hamzeh et al. (2007). Especially the coordination function of a construction logistics centre is interesting because this implies that although the main function of a logistics centre is not applicable for a certain flow type, the coordination can still be done via this logistics centre. In addition, the specific functionalities a construction logistics centre needs, depends on the requirements of the construction logistics structure (Hamzeh et al., 2007). The implementation of logistics centres is a far-reaching measure to intervene in the construction logistics structure. That is why, this measure type is not relevant for small construction projects of for example 100 houses but has its added value for larger urban development and transformation projects.

The operations at a construction logistics centre depends on the functionality of the facility. However, the most basic principles apply to all construction logistics centres (Janné, 2018). Therefore, a regularly named type of a construction logistics centre in literature, the construction consolidation centre (CCC), is highlighted below to give a good sense of how such a facility operates.

Construction consolidation centre

The CCC is a facility mainly used for distribution purposes where material deliveries are consolidated and distributed to one single construction site or several number of sites (Lundesjö, 2011). This is different to the conventional way of delivering construction materials, where the suppliers and carriers directly deliver to the construction site (De Bes et al., 2018). The CCC is an easy to reach distribution facility for construction materials at the edge of the city, near or at a construction site. The goal of a CCC is to receive, store, check and transport construction materials for construction sites in a well-organised manner (De Bes et al., 2018). The concept of the CCC is illustrated in figure 3.

As can be seen in figure 3, the contractors order construction materials at their own suppliers. The suppliers deliver these orders directly to the construction site in the case of full-truckload flows. If the flows are less than truckload, the construction materials are delivered to the CCC. When the materials are delivered at the CCC, the goods are controlled and registered upon entry and stored afterwards in the CCC (Lundesjö, 2015). If the construction materials are necessary at the construction site, contractors can request a delivery of goods to the operator of the CCC. This process is named the call off of materials. This happens according to the JIT pull principle which means that goods are only delivered at the building place when the materials are required (Lundesjö, 2015). Subsequently, the materials will be delivered at the construction site by the operator of the CCC. The empty capacity of the vehicles used to deliver the construction materials can on the way back be utilized to transport waste streams to the CCC.

To summarize, the logistics process of the CCC can consist of five steps: (1) direct transport to the construction site, (2) transport to the CCC, (3) operations at the CCC, (4) transport from the CCC to the construction site and (5) internal logistics activities at the construction site (De Bes et al., 2018).

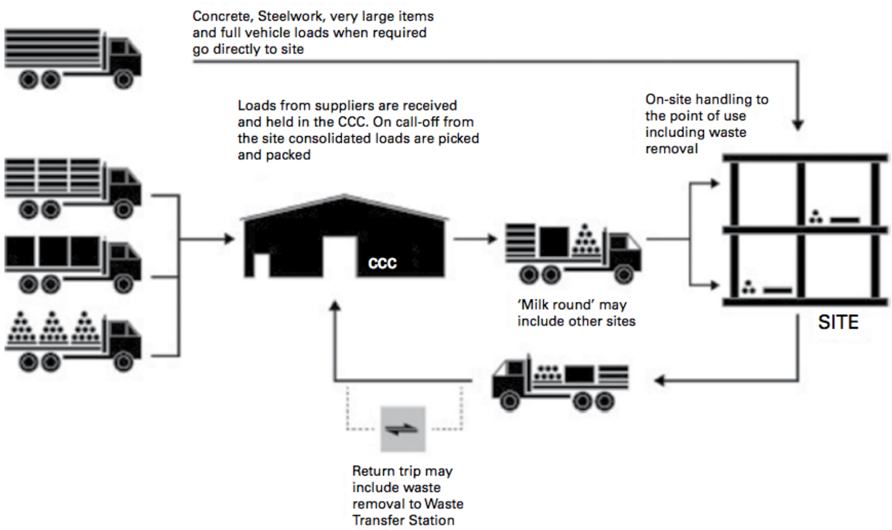

Figure 3: The concept of a construction consolidation centre (Lundesjö, 2011)

The CCC can exist in multiple variants; from a simple storage location to a state-of-the-art logistics centre. In the most extended form, the planning of all the supplies and deliveries to the CCC and the construction site is done by a Logistics Service Provider (LSP) in consultation with other actors such as contractors, sub-contractors, suppliers and freight carriers (Vrijhoef, 2018). The planning should be controlled by the main contractor at the building site. The operations at the CCC can be supported by the use of a Warehouse Management System (WMS) or transport management system (TMS) to assure smooth operations.

Proven benefits construction logistics centre

Multiple studies analyzed the benefits, effects and operations of a construction logistics centre (Lundesjö, 2018). Earlier research to construction logistics centres showed several advantages on social, environmental and operational level (Lease et al., 2008). The most important advantages are the reduction in congestion, noise pollution and harmful emissions (Lundesjö, 2011). In addition, two other positive effects of using a centre, are the increase in waste logistics and the higher productivity on the workplace (Lundesjö, 2015). Some tangible examples are a higher load factor of transport vehicles, less transport journeys and an increase in labour productivity (Lundesjö, 2018) (De Bes et al., 2018)(Lease et al., 2008) (Sullivan et al., 2011). Furthermore, it enables a better organisation of construction material flows between actors (De Bes et al., 2018). The implementation of a logistics centre forces actors in the construction logistics structure to plan the construction logistics on a detailed level. This positively influences the efficiency of construction logistics. Furthermore, all the actors in a construction project can profit from the implementation of a construction logistics centre (Lundesjö, 2011). These results ensure that the construction logistics solution of a logistics centre is widely promoted.

Disadvantages construction logistics centre

Despite the large number of proven advantages of a logistics centre, there are also some drawbacks. Previous studies named a number of disadvantages, especially on a strategic level. First, various actors see the construction logistics centre as an additional expense (De Bes et al., 2018). The use of a construction logistics centre entails extra costs due to the necessary storage and transshipment of construction materials in the centre which requires personnel, equipment, land space and information systems (Janné, 2018). This is especially true for multi-modal transport. Second, the potential savings are difficult to quantify and to divide under all stakeholders (de Vries and Ludema, 2012). The same applies to the potential extra costs. Third, collaboration between different stakeholders is necessary in the field of sharing information and planning (De Bes et al., 2018). This is difficult in the fragmented construction industry. Fourth, an extra node in the supply chain leads to the loss of direct contact between supplier and customer which can cause a greater risk of unreliable deliveries. Some of the disadvantages identified on an operational level are the increase of the time between placing an order and the arrival of this order on the construction site. Plus, the unknown liability for the construction materials when handled in the construction logistics centre (Lease et al., 2008).

1.2 Case IJburg II

The trends of housing shortages and more people migrating to the city are also seen in Amsterdam. Currently, the region Amsterdam has a housing shortage of 42.000 houses (Capital Value and ABF Research, 2019). Thereby, the population growth in Amsterdam is expected to continue in the coming years with 10.000 inhabitants per year which means more than a million residents in 2040 (Gemeente Amsterdam Onderzoek, Informatie en Statistiek (OIS), 2019). All those new inhabitants need places to live. Therefore, the Municipality of Amsterdam is aiming to increase the number of houses by developing new urban districts within the city boundaries. One of these large urban development projects is IJburg II where almost 10.000 new build houses will be constructed together with non-residential facilities to serve the new inhabitants of IJburg II. The project IJburg II is the second part of the urban development project IJburg. As can be seen in figure 4, IJburg II (red encircled) is situated on the east side of Amsterdam. The construction activities of IJburg II will take place on newly sprayed artificial islands in the lake IJmeer-Markermeer: Centrumeiland, Strandeiland (consisting of Muiderbuurt and Pampusbuurt) and Buiteneiland. In addition, the vast majority of the new build houses are planned for Centrumeiland and Strandeiland.

Figure 4: Location IJburg II (Gemeente Amsterdam, 2019b)

1.3 Problem definition

A clear problem definition can be formulated based on the information in subsections 1.1 and 1.2. The housing shortage in Amsterdam in combination with the growing number of people moving to the city lead to the need of new urban development projects in Amsterdam. One of these new urban development projects in Amsterdam is IJburg II. The construction of IJburg II will increase the amount of construction-related transport to, in and from Amsterdam. The construction material flows for the IJburg II project will cause negative effects on the urban environment. The Municipality of Amsterdam is one of the municipalities that imposed more stringent requirements with regard to transport vehicles and has high ambitions to reduce the negative effects on the urban environment in particular on air quality. Furthermore, the Municipality of Amsterdam expects that the construction industry will not come up with a solution of its own and thinks that drawing up stricter strategies for construction logistics alone will not lead to the achievement of the new ambitions related to construction logistics. Also, the Municipality of Amsterdam wants to be assured of smooth construction logistics in the future, even under the stricter strategies. That is why, the Municipality of Amsterdam itself wants to think about new construction logistics structures. However, the Municipality does not know how this new structure should like because to date, these construction logistics structures are not identified. Therefore, designs should be made to explore the possibilities of new construction logistics structures that comply to the new requirements.

The above described problem of the Municipality Amsterdam is not unique for the development of IJburg II. Other equally sized urban development projects, between the 5.000 and 15.000 houses with some non-residential development, will face the same issues as IJburg II. These projects can either be urban development projects or urban transformation projects. Examples of such projects in The Netherlands are: Buiksloterham, Amstel III, Hamerkwartier (all three situated in Amsterdam), Binckhorst (The Hague) and Stadionpark (Rotterdam). However, this project focuses solely on IJburg II, as the opportunity was given to study construction logistics structures for this project.

1.4 Thesis project scope

This thesis explores new construction logistics structures for IJburg II for the supply and disposal of construction materials. The focus is on construction materials used for residential and non-residential construction activities on IJburg II. Therefore, it is also necessary to take into account the ambitions of the Municipality of Amsterdam regarding construction activities for these kinds of development, as the construction material flows depend on the materials and construction methods used. The study covers both residential and non-residential development, because on IJburg II these types of development are equal in material requirements and construction methods. Residential development consists of the building of houses and apartments. Non-residential development comprises the construction of commercial facilities (offices, hospitality, retail) and social facilities (schools, health centres, pharmacies). The supply and disposal of construction materials required for infrastructural projects during the urban development (GWW: Grond, Weg & Waterbouw) are not included in this thesis, because the material requirements differ. Infrastructural development consists of earthworks, road construction and hydraulic engineering (bridges and quay walls).

In this study, Buiteneiland is not taken into account, because the construction plans for Buiteneiland are not yet definite. Moreover, the number of planned houses on Buiteneiland (500) is small compared to the two other islands. In addition, of the three new islands, Buiteneiland is the last island to be built on. This implies that the logistics infrastructure for the two other islands can be used. So, if from now on is referred to the project IJburg II, this includes residential and non-residential development on Centrumeiland and Strandeiland. Besides, this thesis focuses on the supply of construction materials from the supplier or wholesaler to the construction site. The same applies to reverse flows: from the construction site to the waste disposer or other disposal locations.

Furthermore, this study focuses on designing new construction logistics structures by adding construction logistics centres and new types of transport to the conventional construction logistics structure. How the provision of information should take place in this structure is beyond the research scope. In addition, as IJburg II is situated on the waterfront, supply and removal of construction materials by waterborne and road transport is considered. Transport by rail is not included.

Construction logistics structure

The term construction logistics structure is often mentioned in the report and plays an important role in this thesis. Therefore, the term should be defined into more detail so that it is clear what is meant with a construction logistics structure. A construction logistics structure is a system that enables transport of construction materials to and from the construction site. Thus, the structure must be able to supply and dispose all construction materials for a construction project. In addition, it would be beneficial if the construction logistics structure could serve other logistics purposes after the last construction activities.

The construction logistics structure is composed of a number of subsystems. Each subsystem is dedicated to the transport of one type of a generic construction material flow named in subsection 1.1.2. All these subsystems together form one construction logistics structure. In order to demarcate the logistics structure, system boundaries have been established. The logistics structure considered in this thesis runs from the supplier or wholesaler of ready-to-use construction materials to the construction site on IJburg II. This means that any transport from producers of raw materials to the suppliers or wholesalers is not incorporated in this structure.

1.5 Thesis project objective

The thesis project objective can be formulated based on the problem definition in subsection 1.3 and the thesis project scope in subsection 1.4. In order to achieve the thesis project objective, research questions and research objectives were drafted. These are stated and elaborated in subsection 2.2. The thesis project objective is defined below:

> *To design conceptual construction logistics structures for residential and non-residential development on IJburg II that meet the new ambitions of the Municipality of Amsterdam related to construction logistics and construction activities.*

1.6 Thesis outline

The thesis outline is illustrated in table 1. Each section indicates the aim and research question or design objective answered in that particular section.

Table 1: Thesis outline

Section	Aim	Thesis project objective / research question / research objective
1. Introduction	Giving background information, setting thesis context and defining problem	*Which issues require a change in the construction logistics structure and how can the construction logistics structure be improved?*
2. Methodology	Designing and explaining research approach	
3. Project Ijburg II	In-depth analysis construction project IJburg II: construction activities, ambitions, strategies	*How will the construction activities on IJburg II be developed and which strategies and ambitions of the Municipality of Amsterdam in the field of construction logistics and construction activities need to be taken into account in the construction logistics structure?*
4. Requirements Construction Logistics Structure IJburg II	Establishing design requirements and constraints construction logistics structure	*What are requirements of a construction logistics structure for IJburg II?*
5. Design Construction Logistics Structures IJburg II	Generating new designs of construction logistics structures	*To design conceptual construction logistics structures for IJburg II.*
6. Calculation Model & Design Verification	Developing calculation model for vehicle movements, CO_2-, PM_x- and NO_x-emissions; and verifying new designs to the requirements	*To test the conceptual construction logistics structures on the new requirements.*
7. Evaluation Construction Logistics Structures	Identifying key stakeholders, examining feasible designs to the stakeholders' perceptions, taking the first step towards an implementation plan	*To evaluate the feasible construction logistics structures on the stakeholders' perceptions.*
8. Conclusion & Recommendations	Presenting the main findings and lessons learned of this thesis, reflecting on the study, giving directions for further research and presenting the recommendations to the Municipality of Amsterdam	*To design conceptual construction logistics structures for residential and non-residential development on IJburg II that meet the new ambitions of the Municipality of Amsterdam related to construction logistics and construction activities.*

2 Methodology

This section gives an extensive description of the methodology used for this thesis. In this thesis, research was conducted to conceptual designs of a construction logistics structure for IJburg II that comply to the new ambitions of the Municipality of Amsterdam related to construction logistics and construction activities. First, the thesis approach is discussed and the thesis framework is presented. Subsequently, the research questions and research objectives are stated. These are used to achieve the thesis project objective. Thereafter, the thesis deliverable is described. Last, an explanation of the research parts is given and the methods used in these parts are discussed. Besides that, it is also indicated which research questions or objectives are achieved in which part of the thesis.

2.1 Thesis approach

The engineering design approach of Dym and Little (1999) was partly used for this thesis to create conceptual designs of the construction logistics structure for IJburg II. The engineering design approach can be generally divided into five steps of which three active design phases (Dym and Little, 1999). The five steps in the engineering design approach are:

1. Problem definition: the stage in which the problem is framed by clarifying the client's problem statement, objectives, requirements and preconditions
2. Conceptual design: the generation of different concepts to achieve the objective
3. Preliminary design: the examination and evaluation of preliminary choices
4. Detailed design: the refinement of choices made in the preliminary design
5. Design communication: the step to communicate the design, findings and conclusions

As this thesis aims to design and test conceptual designs of construction logistics structures, the fourth step of the engineering design process was not performed in this study. Furthermore, some steps were added to the design engineering process in order to achieve the thesis project objective. Therefore, the design engineering process was adjusted for this thesis. The new developed thesis framework is schematically displayed in figure 5. An explanation of the thesis framework is given in subsection 2.4.

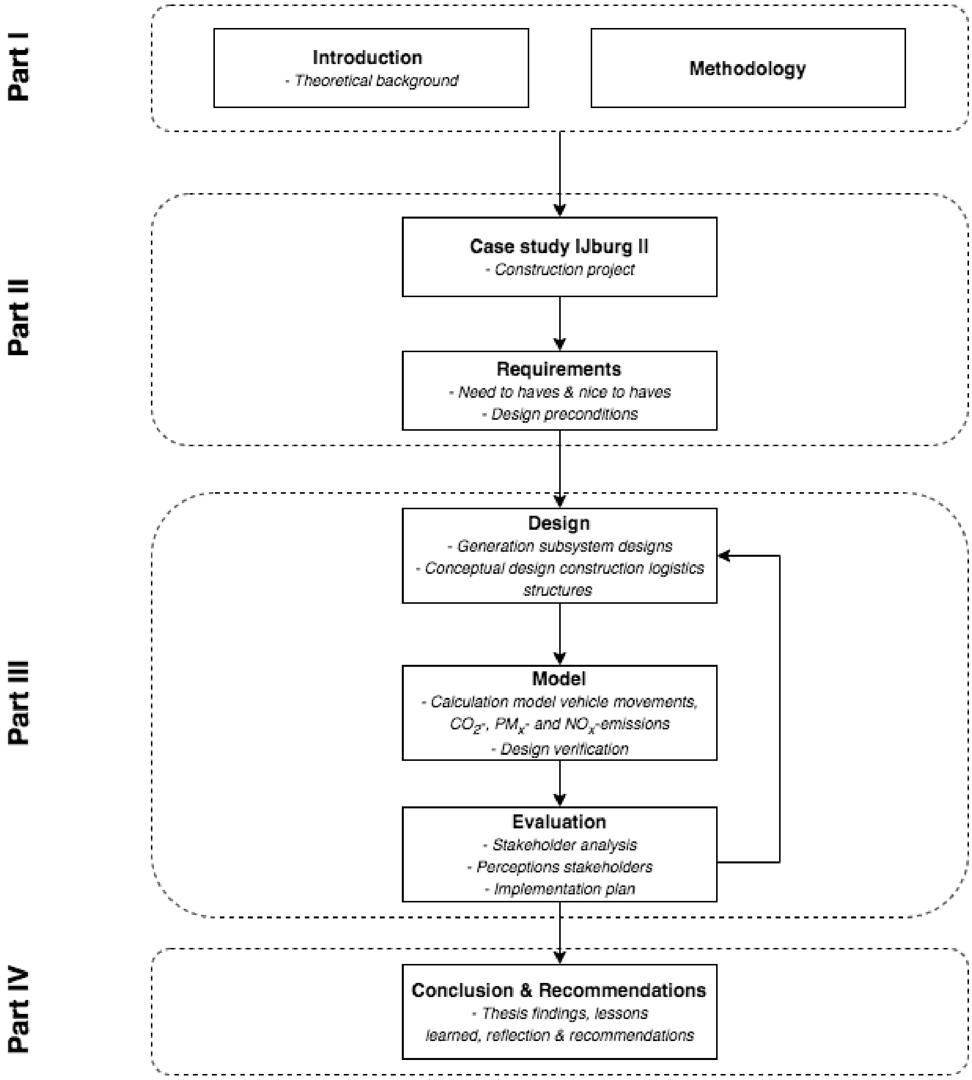

Figure 5: The thesis framework

2.2 Research questions & research objectives

Research questions and research objectives were drafted to reach the thesis project objective stated in subsection 1.5. The research questions and research objectives help in structuring the study and divide the thesis in organized parts. All the questions and objectives are addressed in this thesis. The research questions and objectives can be linked to the steps in the engineering design process of Dym and Little (1999) mentioned in subsection 2.1. The research questions and research objectives with the link to the steps in the engineering design process are stated below:

Problem definition

1. Which issues require a change in the construction logistics structure and how can the construction logistics structure be improved?

2. How will the construction activities on IJburg II be developed and which strategies and ambitions of the Municipality of Amsterdam in the field of construction logistics and construction activities need to be taken into account in the construction logistics structure?

3. What are requirements of a construction logistics structure for IJburg II?

   Conceptual design

4. To design conceptual construction logistics structures for IJburg II.

   Preliminary design

5. To test the conceptual construction logistics structures on the new requirements.
6. To evaluate the feasible construction logistics structures on the stakeholders' perceptions.

The term feasible construction logistics structure is in this context used for a design that meet the new requirements drawn up for the construction logistics structure for IJburg II.

2.3 Thesis Deliverable

The thesis developed conceptual designs of construction logistics structures for IJburg II. These new designs give a picture of how construction logistics structures can be organised in the future by the Municipality of Amsterdam to comply to the new ambitions and stricter strategies in the field of construction activities and construction logistics. Furthermore, a calculation model was made that calculates the vehicle movements and the CO_2-, PM_x- and NO_x-emissions for the newly designed construction logistics structures for IJburg II.

2.4 Thesis parts

The thesis framework in figure 5 divides this study into four phases: the introductory phase (part I), the analysis phase (part II), the design phase (part III) and the communication phase (part IV). The parts are elaborated in detail below with an explanation of the used methods per part and indicating the input and output of these parts. Besides that, it is stated which research question or objective was answered in which thesis part.

2.4.1 Part I - Introductory phase

The aim of the introductory phase is to give context to this thesis and to come up with a clear problem definition and thesis project objective. The introductory phase consists of the thesis introduction and methodology description. In the introduction, background was given about urban development, construction logistics and construction logistics centres based on literature. Literature was searched mainly through Scopus, Google Scholar and the online TU Delft Library. Used search terms were, among others, construction logistics, construction logistics centres, construction consolidation, construction logistics solutions. The problem definition and the design objective could be stated from the background information. The most important output of the introductory phase were the problem definition, the thesis project objective, the research scope, research questions & research objectives and the methods. Therefore, the research question that was answered in this part:

- *Which issues require a change in the construction logistics structure and how can the construction logistics structure be improved?*

2.4.2 Part II - Analysis phase

The objective of the analysis phase is to determine the requirements, preconditions and functions for the construction logistics structure. The analysis phase uses the output of the introductory phase as input. A case study was conducted for the analysis phase of this thesis. The use of a case study was considered appropriate for this thesis as it involves in-depth research in order to generate insights (Bell et al., 2018). In addition, a case study is a good method when a study is performed to a contemporary phenomenon within its real-world context (Yin, 2018). The case study to the project IJburg II resulted in the identification of requirements, preconditions and functions of the construction logistics structure for IJburg II. Used methods during the case study were document analyses, desk research and consultations of various employees of the Municipality of Amsterdam. The identified requirements were classified as need to haves or nice to haves. A requirement is a statement that indicates a capability or function needed by a system in order to satisfy a customer need (Sage and Rouse, 2014). What was considered as a need to have or nice to have was discussed in a consultation group. This consultation group consisted out of five employees of the Municipality of Amsterdam with different roles in the project IJburg II. A list of participants that took part in the consultation group can be found in appendix B. The output of the analysis phase were the design requirements and preconditions for the construction logistics structure. The research questions that were answered in this part:

- *How will the construction activities on IJburg II be developed and which strategies and ambitions of the Municipality of Amsterdam in the field of construction logistics and construction activities need to be taken into account in the construction logistics structure?*

- *What are requirements of a construction logistics structure for IJburg II?*

2.4.3 Part III - Design phase

The goal of the design phase is to generate, test and evaluate three conceptual construction logistics structure designs. The design phase can be divided into three sub-phases: design generation, development model and evaluation. These sub-phases are discussed separately below.

Design generation

In the design generation phase, several designs were generated for the subsystems of the construction logistics structure. The new designs of subsystems were generated with applicable construction logistics centres and new (more sustainable) vehicle types derived from literature. The designs were made with a process flow diagram. These diagrams indicate the travelled road of construction materials from the supplier/wholesaler to the construction site or the other way around. Lastly, three construction logistics structure designs were developed with the newly generated designs for the subsystems. These three structures were composed using different subsystems designs as much as possible. The research objective that was achieved in this sub-phase:

- *To design conceptual construction logistics structures for IJburg II.*

Development model

In this phase, a calculation model was developed in Microsoft Excel to calculate the vehicle movements, CO_2-, PM_x- and NO_x-emissions of the new construction logistics structures for IJburg II. This model estimates the vehicle movements and emissions for the supply and removal of construction materials from the supplier/wholesaler to the construction site. This model was created to check whether the new generated designs of a construction logistics structure for IJburg II comply to the requirements. The designs were tested on the requirements in the design verification. The three developed construction logistics structures were tested against the earlier drafted requirements both qualitatively and quantitatively (with calculation model). The research objective that was achieved in this sub-phase:

- *To test the conceptual construction logistics structures on the new requirements.*

Evaluation

In the evaluation phase, the designs that comply to the new requirements of the construction logistics structure for IJburg II were evaluated. The designs were examined on the perceptions of important stakeholders towards the new designs, as Ballantyne et al. (2013) stated that perceptions of stakeholders are crucial for implementing new logistics systems. In addition, Macharis et al. (2012) stressed that the implementation of a construction logistics structure is difficult due to the complex relationship between stakeholders and de Vries and Ludema (2012) even stated that a construction logistics solution seems impossible without proper coordination and collaboration between multiple actors. For the identification of important stakeholders, a stakeholder analysis was performed. The interests of different stakeholders were identified by doing desk and literature research; and during preliminary discussion groups with multiple stakeholders. A power-interest grid and a stakeholder influence diagram were used to examine the power and influence of multiple stakeholders. According to Bryson (2004), these are suitable methods for the identification of power and influence of stakeholders. The six stakeholder groups whose perceptions have been evaluated were: 1. the Municipality of Amsterdam, 2. contractors, 3. project developers, 4. road freight transporters, 5. waterborne freight transporters and 6. new inhabitants. The correctness of this evaluation is checked by means of a reflection in the consultation group. Last, based on the stakeholders' perceptions, the first steps towards an implementation plan were taken. The stakeholders' perceptions were used in a stakeholder-issue interrelationship diagram to identify which stakeholder groups have issues with what part of the new construction logistics structure. These results can be used to specifically engage stakeholders for implementation.

- *To evaluate the feasible construction logistics structures on the stakeholders' perceptions.*

2.4.4 Part IV - Communication phase

The objective of the communication phase is to present the main findings and lessons learned of this thesis, to critically reflect on the study, to give directions for further research and to present recommendations to the Municipality of Amsterdam. The thesis findings were found by concluding the research questions, research objectives and the thesis project objective. The lessons learned subsection depicts conclusions from this study that also apply to other similar development projects in the Netherlands. A reflection was written to put the findings from this thesis into perspective. The directions for further research were drafted based on knowledge gaps identified in the reflection. Last, recommendations to the Municipality of Amsterdam were given on the basis of the thesis findings.

2.5 Relevance of research

The relevance of this thesis can be divided in a scientific relevance and a societal relevance. Both values of this thesis are explained below.

2.5.1 Scientific relevance

This thesis can be placed in line with other case studies aiming to improve construction logistics. Several case studies focused on the logistics performance and efficiency of construction logistics. The case study of Ying et al. (2014) addressed the efficiency in transporting construction materials by using the number of vehicle movements as performance indicator. Ekeskär and Rudberg (2016) focused on the deployment of a third party logistics provider in a large construction project to analyze its resulting effects on the logistics performance. Sundquist et al. (2018) aimed to explore strategic measures to reorganize construction logistics by improving the connections between on-site and off-site logistics for a higher efficiency. Case studies from De Bes et al. (2018) and Vrijhoef (2018) looked more closely into measures for the improvement of the construction logistics structure. However, what is underexposed in these case studies is how these improvements influences the environmental and social performance of construction logistics structures. The case study in this thesis tries to fill this gap by focusing more on the environmental and social performance of new construction logistics structures.

2.5.2 Societal relevance

The societal relevance can be explained by the fact that as a result of this thesis it becomes more clear what effects a new construction logistics structure has on the urban environment. The outcomes of this exploratory study to new construction logistics structures can be used as a basis for the implementation of more sustainable structures. This most certainly leads to positive consequences for society as the negative impact of construction logistics on the urban environment is likely to decrease. A number of positive consequences could be the reduction of congestion and polluting emissions and the increase in traffic safety.

3 Project IJburg II

This section aims to give answer on the research question: *how will the construction activities on IJburg II be developed and which strategies and ambitions of the Municipality of Amsterdam in the field of construction logistics and construction activities need to be taken into account in the construction logistics structure?*

Therefore, all important aspects of the construction activities on IJburg II are identified in this section. This should clarify when, how much and how will be constructed on IJburg II. Besides that, the to be generated construction material flows are analyzed. The last part of this section is used to explore the ambitions and strategies of the Municipality of Amsterdam related to construction logistics and construction activities.

3.1 Urban development

The construction project of IJburg II is an area development project at the edge of the city Amsterdam. IJburg II is a residential neighbourhood built on artificial islands in the lake 'IJmeer' and is part of the borough Amsterdam Oost. It is the second part of the IJburg project which is part of a large area development project initiated by the Municipality Amsterdam in 1996. At the moment, already 24.000 people live at IJburg I. By the end of the construction activities, IJburg must totally offer place to 45.000 people to live. The construction of IJburg I is largely finished and consists of the artificial islands Haveneiland, Rieteiland and Steigereiland. IJburg II includes the development and construction of Centrumeiland, Strandeiland and Buiteneiland. Centrumeiland has already been sprayed, while the spraying of Strandeiland started in 2018. Centrumeiland will offer place to 1500 houses and Strandeiland to 8000 houses (Gemeente Amsterdam, 2016) (Gemeente Amsterdam, 2019b). The land reclamation of Buiteneiland will start in 2023. The idea of Strandeiland is that it will be a place with a green and sustainable character intended for recreation, sports and culture purposes with a maximum number of 500 houses.

The development of IJburg II is an interesting but complex project, because all the infrastructure, facilities and houses need to be realized in the same period of time. The urban development of IJburg II will take some years before it is finished. The construction activities for Centrumeiland are planned to start in 2020 and the construction works for Strandeiland will last till 2038. This means a combined construction time of 18 years for these two islands. The construction works will be done in phases depending on the setting times of the reclaimed land. The construction activities can mainly be divided into four construction phases: site preparation, substructure construction, shell construction and final construction as described in subsection 1.1.1.

As described in subsection 1.4, the choice is made to focus on the construction logistics for residential and non-residential development for Centrumeiland and Strandeiland. The public infrastructure is not incorporated in this thesis. However, the construction materials necessary for residential and non-residential development differ in the first three construction phases not that much from construction materials necessary for the construction of public infrastructure. This would concern materials such as ready-mixed concrete, sand, minerals and heavy elements. Construction logistics structures made for these phases may therefore also be used for these material flows, but this should be examined in more depth.

3.2 Construction activities for urban development

In this subsection, the characteristics of the houses and facilities are described for Centrumeiland and Strandeiland, followed by the construction sequence. Thereafter, the construction phases to be completed for each residential or non-residential structure are identified together with the core construction activities in each phase.

3.2.1 Building characteristics & construction sequence

Centrumeiland

Houses and Facilities

In total, 1500 houses will be built on Centrumeiland. The average single-family houses have a gross floor area of 253 m2 (BVO). There are no large facilities planned at Centrumeiland, only some small neighborhood facilities such as an elementary school, a bakery and a butcher. This will cover around 27.000 square meters (BVO) of commercial and social facilities. The building height at Centrumeiland can vary between the four and six floors (Gemeente Amsterdam, 2016). From this can be concluded, that the majority of the buildings will be of a residential nature.

Construction sequence

The spraying of Centrumeiland began in 2013 and was completed in 2015. Before the construction activities could start, the soil should set and the island needs to be prepared for construction works by means of site preparation. The site preparation started late 2017 with elevating some of the building plots to the correct ground level and the construction of roads (Gemeente Amsterdam, 2016). The construction activities started on May 15th, 2019 and will most likely last until 2026 (NUL20, 2019). The construction works are divided into four tranches. The division of these construction stages can be seen in figure 6. As can be seen in this figure, the building activities will start at the south side of the island. Moreover, the building plots closest to IJburg I will be built first. Each tranche is almost equal in size and consist of around 375 houses. The plan is to deliver 250 houses per year. This means that construction activities for one tranche will take about a year and a half. Furthermore, the first inhabitants already live at Centrumeiland when a large part of the construction work is still to be done. Thus, nuisance related to construction activities and construction logistics needs to be minimized for the new residents (Kuiper, 2020).

Figure 6: Construction sequence Centrumeiland (Gemeente Amsterdam, 2016)

Strandeiland

Houses and facilities

Strandeiland will offer place to a total of 8000 new houses, 3000 homes in the Muiderbuurt and 5000 homes in the Pampusbuurt. Strandeiland is designed with an average density of 60 houses per hectare and offers space to 1.000.000 m2 of gross floor area (BVO). 880.000 m2 is destined for houses and about 120.000 square meters (BVO) will be reserved for commercial and social facilities. At the moment, the planning is that 55.000 m2 will be used for social facilities and 45.000 m2 for facilities with commercial purposes (Gemeente Amsterdam, 2019b). 20.000 m2 still does not have a destination and is reserved to cover any shortfall of space. Social facilities includes, among others, nine elementary schools, a high school and a health centre. Commercial facilities consists of offices and places for the hospitality and retail industry. Building height at Strandeiland varies between the two and four floors for the Muiderbuurt and between the four and six floors for the Pampusbuurt (Gemeente Amsterdam, 2019b). The building height per building for Strandeiland can be found in Appendix C.

Construction sequence

The process of land reclamation for Strandeiland started in August 2018 and still is in full swing. The spraying of land is tiered in two parts. The first phase consists of land reclamation for half of the two neighborhoods, the Muiderbuurt and the Pampusbuurt. First step of land reclamation is planned to be finished in May 2020. The second phase of land spraying will realize the final halves of these two neighborhoods. Starting date for the second phase has not yet been determined. The two phases of land reclamation with the planned delivery date can be found in Appendix C. It is expected that the settling time for the Pampusbuurt is much longer (3 years) than for the Muiderbuurt (1 year) due to bad soil conditions (Gemeente Amsterdam, 2019b). The plan is to start building houses at Strandeiland at the end of 2022 in the Muiderbuurt. This means that 2021 and a part of 2022 can be fully used for site preparation in the Muiderbuurt. In this way, the Pampusbuurt has the required settling time of 3 years. The plan is to build around 500 houses per year which means that construction activities will be finished in 2038. Figure 7 illustrates the construction sequence on Strandeiland. As can be seen in this figure, the construction activities shift from east to west on the island, with a few exceptions.

As is the case for centrumeiland, a large number of the residents of Strandeiland will already be living there during the construction activities. This will have to be taken into account in the design of the construction logistics structure. Another point of attention for the design is that potential logistics facilities should not hinder the construction process and cannot be located in the middle of a new residential area. In addition, there is no logistics structure yet for IJburg to supply future companies on IJburg.

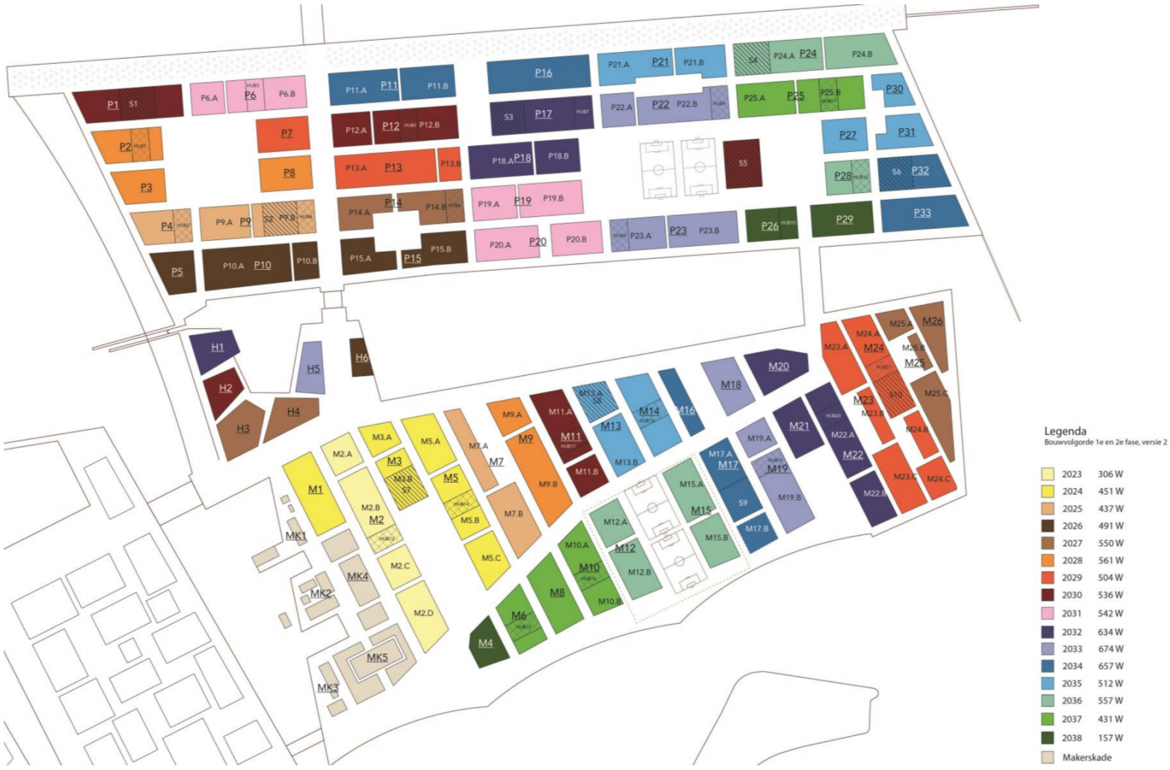

Figure 7: Construction sequence Strandeiland (Gemeente Amsterdam, 2020c)

3.2.2 Construction phases buildings

Both Centrumeiland and Strandeiland are residential and non-residental development projects. This means that for the development of the buildings on IJburg II all four construction phases described in subsection 1.1.1 should be completed. The core construction activities for IJburg II per construction phase are explained below.

1. **Site preparation**: The excavation and raising of the soil. Since the artificial islands are sprayed with sand, the soil will consist mainly of sand.

2. **Substructure construction**: As the bearing capacity of the soil on IJburg II is not high, the structures should be founded on piles. Also, foundation beams and other foundation elements will have to be laid.

3. **Shell construction**: Construction of the shell with, among others, walls, roof, dormers, window frames.

4. **Final construction**: The finalization of the structures with mainly indoor construction activities such as carpentry, stucco and painting.

3.3 Construction method

The way in which the construction activities are carried out are important for the transport system. For example, houses produced on site with in-situ cast concrete require different types of material deliveries than prefab produced houses. The construction method strongly depends on the requirements imposed on building materials for example by the Municipality or project developer and allowed construction techniques on IJburg II. Often, the availability of construction space also plays a role in this, but is less important in this project as there is generally enough available building space. Therefore, these two aspects are analyzed in this subsection.

3.3.1 Construction materials

The goal of the Municipality of Amsterdam is to build as sustainable and circular as possible on IJburg II. This is also reflected in the guidelines for material use on Centrumeiland and Strandeiland. A number of documents describe the strategy and ambitions in the field of material use. These documents with the most relevant ambitions and policy strategies are discussed below.

Amsterdam Circulair 2020-2025

For the development of IJburg II, the Municipality of Amsterdam mainly adheres to the guidelines for construction materials described in the document 'Amsterdam Circulair 2020-2025' (Gemeente Amsterdam, 2020a). This document is set up by the Municipality of Amsterdam in order to come up with clear strategies and ambitions in the field of circularity. The concept circular economy aims to prevent waste by maintaining the value of products, parts and materials as long as possible in a closed loop (Gemeente Amsterdam, 2020a). In this way, less waste is produced which is beneficial for the environment. In addition, it is expected that this concept will reduce the costs of material without sacrificing the quality. The ambition of the Municipality of Amsterdam for 2030 is to use 50% less primary resources (raw materials that have never been used or recycled before) and for 2050 to be fully circular. In the field of circularity, the Municipality stakes on three value chains: Food and organic reverse flows, consumer goods and the built environment. Particularly, the circular ambitions and strategies for the built environment are relevant for this thesis. These are elaborated below and furthermore is indicated from which year it should take effect.

- **2022**: All designs for urban development projects, such as IJburg II, should be based on circular criteria.
- **2023**: All construction activities for residential, non-residential and infrastructural development should be evaluated on circular and societal criteria. This strategy should enhance the use of recycled or bio-based materials. These criteria can be applied to land issue in tenders and procurement (Gemeente Amsterdam, 2020a). The Municipality has an important role as land publisher and commissioning authority in this respect.
- **2030**: 50% of the construction materials used during construction activities should be circular
- **2050**: 100% of the construction materials used during construction activities should be circular.

Stedenbouwkundige plannen Centrumeiland and Strandeiland

In both urban development plans (stedenbouwkundige plannen) for Centrumeiland and Strandeiland is stressed that project developers and contractors should be directed to local, re-usable and bio-based materials or high quality re-used materials. Examples of these type of materials are FSC-wood, circular bricks, green concrete (concrete extracted from recycled materials) or steel. Next to that, should sand and soil flows be re-used locally, preferably even on the islands. To stimulate the use of the above mentioned materials, the Municipality of Amsterdam aims to implement a strategy to reward the use of these kind of materials in tenders (Gemeente Amsterdam, 2019b). The importance of waste separation also comes forward, since 10% of the used construction materials will be waste (Gemeente Amsterdam, 2019b). Waste separation should be done at the construction site in six large waste flows. As a result of this maximum waste separation, the residual flows are no longer waste, but raw materials for other construction materials. A joint waste collection on the island can enhance this ambition. In consultation groups with the Municipality of Amsterdam came forward that the Municipality highly values the circular ambitions on IJburg II. A dedicated area to store circular materials on IJburg II was seen as a necessity for circular construction activities.

From the above can be concluded that the requirements related to construction materials will change during the construction project of IJburg II. As the construction project progresses, more circular materials will have to be used. A clear milestone for this is the year 2030. from that moment on, 50% of the building materials will have to be circular. This fact should be taken into account when designing a construction logistics structure, because this probably asks for a shift in construction methods. Large-scale circular construction with ready-mixed concrete is for example not yet possible, making a shift to wooden or other circular materials more plausible. In accordance with the consultation group, it was decided that the standard to use 50% circular materials in construction activities starts in 2030 instead of that all structures delivered in 2030 need to be constructed with 50% circular materials.

3.3.2 Construction techniques

The to be applied construction techniques on IJburg II are depended on the allowed construction techniques on the islands and the trend in the field of construction techniques. The BLVC-kader (Bereikbaarheid, Leefbaarheid, Veiligheid & Communicatie kader) describes a number of points for IJburg II of how to build and how not to build. That is why, the BLVC-framework is discussed in this subsection just as new trends for construction techniques.

BLVC-kader IJburg II

A number of points are named in the BLVC-kader that are relevant for the construction techniques on IJburg II (Kuiper, 2020). Anyone who builds on IJburg II, from private builder to large contractor, must comply to these rules. The most important issues in the BLVC-kader related to construction techniques are listed below:

- Noise and vibrations must comply with the legal requirements of the Building Act. In addition, noise and vibrations caused by the construction works should be kept to a minimum.
- The installation and removal of foundation structures and sheet piling must be carried out using low-noise and low-vibration techniques. Techniques such as vibrating or pile driving are therefore inadmissible.
- Temporary storage of construction materials must be limited. Storage of small materials is only allowed in containers within the boundaries of the construction area.

- Construction tools must comply to the actual emission standards or direct predecessor of these emission standards. From **2019**, only construction tools phase V are allowed in Amsterdam Team Luchtkwaliteit Gemeente Amsterdam (2019). From **2025**, the strategy is that all the construction tools are emission-free if the technique and enforceability allow it. In addition, the Municipality of Amsterdam has the strategy to encourage more sustainable construction tools until emission-free, in 2025, will be the standard.

New trend in construction technique

In recent years, one of the biggest trends in construction techniques is the industrialisation of the construction process (van Merriënboer et al., 2012). The reason for this trend is the need to a higher and more constant quality of construction works, lower costs and a more controllable construction process. This causes a shift of the construction activities from the construction site to production locations or factories (van Merriënboer et al., 2012). Given the recent article of Verbraeken (2020), this trend will only continue to develop. Circumstances such as the high demand for new-build housing and a shortage of labour, only serve to encourage this development (Verbraeken, 2020). The consequences for the way of constructing are large, since construction sites transform into assembly places. In addition, less construction personnel is needed and the construction time will decrease.

The industrialisation of the construction process has also some consequences for construction logistics. Since more prefabricated elements are produced in factories, more transport of large and heavy construction elements will take place to the construction site. In addition, Just-In-Time deliveries will become more important because generally spoken there is not enough space at construction sites to store many large construction elements. Lastly, the largest material flows will shift from the construction site to suppliers of prefabricated elements (van Merriënboer et al., 2012).

Scenarios construction method

From the gathered information of the case study can be concluded that there are a lot of uncertainties concerning the construction method. Different scenarios can be drawn up from the information above, making combinations with each uncertainty. Variations can be made in construction time, construction techniques and whether or not to apply circular building materials. However, this leads to a multitude of scenarios. For this thesis, it is important to determine the most plausible scenario. Therefore, it was decided to outline the most likely scenario for the construction method.

Plausible scenario

Until 2030, buildings are constructed in the conventional way: using ready-mixed concrete and prefab elements. This is called the hybrid construction method. Prefabricated piles are not used because construction activities should be quiet and vibration-free. Therefore, in-situ cast piles will be used for the foundation. From 2030, circular construction materials such as wood are used for the structure of buildings. Moreover, this is in line with the trend of the industrialisation of the construction process. In-situ concrete piles are still used for the foundation because other viable vibration-free solutions, with more circular materials than ready-mixed concrete, are not available. Furthermore, it is assumed that the construction planning will not be delayed because there is a great need for new houses.

3.4 Generated construction material flows

An analysis was performed to the construction material requirements of residential and non-residential development to identify which construction material flows are generated by the construction of IJburg II. This analysis was done by estimating the material requirements of an average house. An estimate was made based on general construction costs for a new build house and an example building specification (Cobouw, 2020) (Stabu, 2018).

The required construction materials for the construction of a new build house were classified in a generic construction material flow per construction phase. For this purpose, the six generic construction material flows in subsection 1.1.2 were used. In addition, a distinction was made for construction materials that will be transported to the construction site and construction materials that are removed from the construction site.

The results of this analysis can be found in table 2. The first column indicates the construction phase, the second column the products transported towards the construction site and the third column the materials from the construction site. The last column displays the generic construction material flows that should be transported to or from the construction site in that particular construction phase. The last column was drafted based on the information of the second and third column. Table 2 gives a clear indication of the generic construction material flows that should be transported by the construction logistics structure per construction phase. These findings can be used in the determination of the appropriate construction logistics centres per construction phase.

Table 2: Overview construction material flows IJburg II

	Construction materials towards construction site	**Materials from construction site**	**Type of material flow**
Preparation construction site		Sand and soil	• Reverse flows
Substructure construction	Prefab, ready-mixed concrete and steel piles; sheet piles; reinforcement steel; steel, concrete	Sand and debris.	• Large time-critical full-truckload flows • Large non time-critical full-truckload flows • Reverse flows
Shell construction	Ready-mixed concrete; mortar; gypsum blocks; sand-lime brick; bricks; prefabricated wall, floor and roof elements; wooden wall, floor and roof elements; metal plates, profiles and cables; insulation material; chimneys; wooden stairs; window frames; doors; dormers and glass.	Debris; plastics; packaging material; cardboard and glass.	• Large time-critical full-truckload flows • Large non time-critical full-truckload flows • Non time-critical small less than truckload flows • Reverse flows
Final construction	stucco mortar; tiles; ceiling and wall systems; wood; paint; wallpaper; floor coverings; gutters; indoor drains; plumbing; electrical, water and gas installations; installation material.	Debris; plastics; packaging material; cardboard and glass.	• Non time-critical small less than truckload flows • Non time-critical packages • Time-critical rush orders • Reverse flows

Materialisation of new-build houses

The materialisation of an average new build house was investigated to get a better insight in which materials are used most for the construction of new build houses. Of course, the materialisation depends on the construction method but this analysis should give a rough indication of the size of construction materials per house. For this purpose, the research of Arnoldussen et al. (2020) was used. This study analyzed the construction material requirements for a number of different new-build building types. From this it appeared that roughly 80% of the necessary construction materials in kg consists of concrete. This means that either ready-mixed concrete or concrete elements form the largest construction material flows for new-build houses. Ready mixed-concrete is an challenging material to transport due to the time component. This type of concrete should be transported within a few hours to the construction site, otherwise the concrete starts to cure. Other relevant construction material flows in weight are brick (4%), wood (3%) and iron (4%) (Topsector Logistiek, 2018) (Arnoldussen et al., 2020). It should be noted that these percentages are based on weights. If for example is looked at volumes for construction flows, the percentages can be totally different. However, what clearly can be stated from this analysis is that concrete is still the most used construction material in the construction of new-build houses.

3.5 Ambitions and strategies construction logistics

This subsection explores the ambitions and policy strategies of the Municipality of Amsterdam related to construction logistics for IJburg II. As there is no uniform document that describes the ambitions and policy strategies for construction logistics, several policy documents were consulted. The analyzed policy documents are the Actieplan Schone Lucht (Program Clean Air), Nota Varen deel 2 (Note Sailing Part 2), the Agenda Amsterdam Autoluw (Agenda Traffic-restricted Amsterdam) and the BLVC-kader (BLVC-framework). The relevant points out of these policy documents related to construction logistics are highlighted below per policy document. Furthermore, three consultation groups were held with various internal stakeholders of the Municipality of Amsterdam in the field of sustainability, project management and logistics to discuss the ambitions and strategies on IJburg II. Appendix B contains a list of participants to these sessions.

Actieplan Schone Lucht

With the Actieplan Schone Lucht, the Municipality of Amsterdam tries to improve the air quality in and around the city. Successfully, the air quality considerably improved in the last decade (Team Luchtkwaliteit Gemeente Amsterdam, 2019). The European standard for nitrogen oxide (NO_x) is met in most places in the city, while for particulate matters (PM_{10} and $PM_{2,5}$) the standards are met in the entire city (Team Luchtkwaliteit Gemeente Amsterdam, 2019). However, the Municipality strives to meet the more strict standards of the World Health Organization (WHO) of annual concentration for NO_2 (40.5 µg/m^3), PM_{10} (20 µg/m^3) and $PM_{2,5}$ (10 µg/m^3). The goal is to meet the air quality standards of the WHO in 2030 for nitrogen oxide and particulate matters. Furthermore, the aspiration of the coalition agreement of the Dutch government is a 55% reduction of CO_2-emissions.

The ambition of the Municipality of Amsterdam is 'clean air for all inhabitants'. The Actieplan Schone Lucht describes strategies that can be taken by the Municipality to achieve this ambition. A large proportion of emitted CO_2-, NO_2- and PM_x-emissions can be attributed to transport movements. Therefore, the Municipality is committed to increase the sustainability of the polluting sources such as vehicles, construction tools (loader, excavator and cranes) and diesel generators. This is an efficient approach because most of the trucks and construction tools run on diesel, so they contribute heavily to the air pollution in Amsterdam. This method is also effective because the Municipality is able to directly influence the policy strategies in this field. To accomplish all the ambitions in the field of clean air, the Municipality aims for emission-free transport in the city and a reduction of emissions by polluting sources such as construction tools (Team Luchtkwaliteit Gemeente Amsterdam, 2019).

The transition to an emission-free city is conducted in phases. This means that more and more areas, transport movements and polluting sources will need to be emission-free. The measures in the Actieplan Schone Lucht that have a large impact on the construction logistics on IJburg II, are the ambitions and strategies regarding the freight transport by vans, trucks and water. The most relevant points of the Actieplan Schone Lucht are listed below (Team Luchtkwaliteit Gemeente Amsterdam, 2019). The year in which the ambition or strategy takes effect is also indicated.

- **2020**: The environmental zone in Amsterdam for all vehicles including trucks and vans will be expanded from November 2020. The new boarder is the ring highway A10, IJburg II is not covered by this regulation (Gemeente Amsterdam, 2020b). In this environmental zone, only diesels with an European emission standard higher than EURO 4 are allowed in this area (the higher the number the cleaner the vehicle). This strategy should make it less attractive to drive in outdated vehicles.

- **2022**: The access requirements for the environmental zone will be tightened to vehicles with EURO 6 standards.

- **2025**: The environmental zone will from now on be emission-free.

- **2030**: The entire urban area of Amsterdam, including IJburg II, emission-free. IJburg needs to be emission-free from 2030. However, large urbanized areas such as IJburg can always be added to the environmental zone. This also happened to other areas such as the Houthavens and Zeeburgereiland. This uncertainty needs to be taken into account.

Nota Varen Deel 2

The document Nota Varen Deel 2 describes the latest sailing policy of the Municipality of Amsterdam. Starting point for this policy is a sustainable, balanced and smart use of waterways in and around Amsterdam for different purposes, including freight transport (Gemeente Amsterdam, 2019a). Amsterdam is actively promoting waterborne transport by water to relieve the burden on the urban road transport system. A number of strategies and ambitions in this document are relevant for construction logistics by water for IJburg II and are therefore noted below.

- **2025**: Emission-free waterborne freight transport in the environmental zone from 2025 with a transition phase of five years till 2030 (Gemeente Amsterdam, 2019a). With the comment, that is should be technologically feasible.

- **2030**: All waterborne transport within the city boundaries emission-free, including the waters around IJburg II. Furthermore, zero-emission inland shipping is an important pillar in the Dutch climate agreement (van Rijn et al., 2020). In 2030, 150 inland barges should be emission-free.

Agenda Amsterdam Autoluw

In the document 'Agenda Amsterdam Autoluw' a number of ambitions are described in the field of construction logistics. The goal of this document is to establish a spacious, livable and good accessible city (Gemeente Amsterdam: Verkeer en Openbare Ruimte, 2020). One of the five objectives stated in this document can directly be linked to construction logistics: cleaner air, less noise hindrance and a better traffic safety. To achieve this ambition, the Municipality of Amsterdam aims to increase the number of policies on construction logistics. In recent years, the Municipality already developed some strategies focusing on smart and clean construction logistics. Examples of these strategies are construction logistics award criteria during tenders, stimulating waterborne freight transport and making use of multi-modal logistics centres (Gemeente Amsterdam: Verkeer en Openbare Ruimte, 2020). The Municipality intends to implement more of these construction logistics strategies in the near future.

BLVC Kader IJburg II

The BLVC framework (Bereikbaarheid, Leefbaarheid, Veiligheid & Communicatie kader) describes the measures, responsibilities and agreements up and around construction sites. The plan states how to minimize the hindrance to the surrounding environment. Since the long development time of IJburg II, it is of great importance to reduce the amount of nuisance and bottlenecks caused by construction logistics during construction activities (Kuiper, 2020). A number of points in the BLVC Kader are related to construction logistics. The most relevant strategies are explained below (Kuiper, 2020). Important to mention, the BLVC Kader can always be adjusted to new construction circumstances or changing insights by the Municipality of Amsterdam. However, the global construction guidelines will remain unchanged for the entire construction period.

- A CO_2-reduction of at least 25% due to transport movements.
- Construction and residential traffic must be separated at all times to ensure road safety.
- Routing of construction traffic should be based on the least possible nuisance, using the preferred access route as much as possible. This is the route S114 via the Muiderlaan and the Fortdiemerdamweg.
- Through roads and through routes may not be obstructed. Construction traffic is not allowed to wait or stop on public roads.
- The window times for loading and unloading road transport are between 9:00 AM and 3:00 PM. Furthermore, the deliveries must be reported and brought by appointment.
- The loading, unloading and storage of construction materials must be done within the boundaries of the construction site. Loading and unloading shall be permitted in public areas provided that it does not hinder other traffic or cause nuisance. This is only allowed in consultation with the construction coordinator.

Consultation group

The consultation groups were held to define the ambitions and strategies regarding construction logistics and construction activities more clearly. For example, the definitions for emission-free transport and circular building were discussed. These definitions are explained in section 4. In addition, the ambitions and strategies found in the several policy documents were evaluated for the IJburg II project. What else came up in this group, was the desire of the Municipality of Amsterdam to use parts of the construction logistics structure for logistics purposes after the construction project. In the future, IJburg II needs to be supplied with freight and reverse flows need to be disposed. For financial reasons, it would be preferable to use the construction logistics infrastructure for this logistics purpose in the future.

3.6 Timeline construction activities and strategies

A timeline was drawn up in order to obtain a clear overview of the construction activities and strategies per time period. Figure 8 displays the timeline with essential time periods for this thesis in the development of IJburg II. These project milestones are in a later stadium of the thesis used to develop a calculation model.

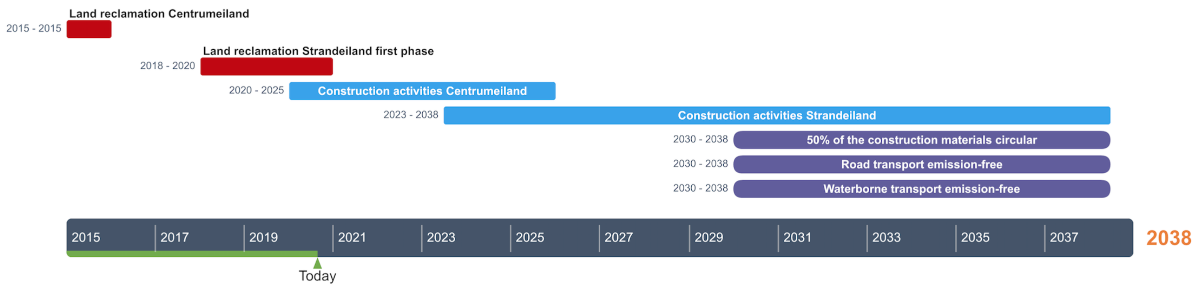

Figure 8: Timeline construction activities and strategies IJburg II

3.7 Sub-conclusion

The construction activities on IJburg II will take place from 2020 until 2038. First, Centrumeiland will be constructed followed by Strandeiland. However, there will be an overlap in construction activities for the two islands, as the construction activities for Strandeiland start in 2023 and the construction activities for Centrumeiland last until 2025. In principle, the construction activities shift from west to east across the islands, with a few exceptions. For the majority, the construction activities exist of residential development but there will be also a little non-residential development. All the four construction phases must be completed on IJburg II, as it is an urban development project.

The Municipality of Amsterdam stimulates the use of circular construction materials on IJburg II. From 2030, 50% of the used construction materials for construction activities should be circular. Therefore, it can be concluded that there will be a shift in material usage from conventional construction materials to circular construction materials during the construction activities. The construction techniques that can be used on IJburg II are limited in particular by the rules on low-noise and low-vibration construction techniques. This means that the construction technique to drive piles is not possible. In addition, it can be concluded that construction activities shift from the construction site to factories during the construction period of IJburg II due to the industrialisation of the construction process.

Four policy documents of the Municipality of Amsterdam state relevant ambitions and strategies related to construction logistics: Actieplan Schone Lucht, Nota Varen Deel 2, Agenda Amsterdam Autoluw and BLVC-kader IJburg II. Important ambitions for construction logistics are ambitions related to the emissions of CO_2-, PM_x- and NO_x, improvement of traffic safety, increase in waterborne freight transport and reduction of congestion. Strategies that need to be taken into account are emission-free road and waterborne transport from 2030 on and around IJburg II and restricting emission-standards for road vehicles.

4 Requirements Construction Logistics Structure IJburg II

The aim of this section is to answer the research question: *what are requirements of a construction logistics structure for IJburg II?*

In this section, the design preconditions and requirements of the construction logistics structure for IJburg II are specified. The design preconditions specify the elements that limit the design solutions. This could be factors such as environmental limits, legislative and regulatory standards (Leonard, 1999). A requirement is a statement that indicates a capability or function needed by a system in order to satisfy a customer need (Sage and Rouse, 2014). A requirement should state what the system has to do, but should not indicate how the system has to do it (Sage and Rouse, 2014). Two types of system requirements can be distinguished: the mandatory requirements (also called constraints) and trade-off requirements (also called objectives) (Sage and Rouse, 2014). Both requirements are used in this thesis. The mandatory requirements, from now on referred to as **need to haves**, define the necessary capabilities that a system must have in order to be acceptable. The trade-off requirements, from now on referred to as **nice to haves**, specify capabilities that would make the customer happier (Sage and Rouse, 2014).

The design preconditions and requirements (need to haves and nice to haves) were drawn up based on information gathered in the case study in section 3. In section 6, the developed construction logistics structures are checked on the requirements. A number of the requirements are tested quantitatively making use of a newly developed calculation model, the others qualitatively.

4.1 Design preconditions

In this thesis, a number of design preconditions were taken into account which demarcate the design space for the construction logistics structure. The design space is partly limited by strategies related to construction logistics. These strategies were identified in subsection 3.5. An important moment in these strategies for IJburg II is the year 2030. From this year on, the strategies relating to construction logistics on IJburg II are becoming much stricter. Therefore, a division is made in the the design preconditions valid for the period 2020-2029 and 2030-2038. The design preconditions which are valid for the entire construction period from 2020 to 2038 are indicated as generic design preconditions. The generic design preconditions and design preconditions for the two different periods are listed below.

Generic design preconditions 2020-2038

1. The construction logistics structure must transport the construction materials for residential and non-residential structures from the supplier or wholesaler to IJburg II by road or waterborne transport.
2. The construction logistics structure must be technologically feasible from 2020. This precondition is retrieved from meetings with consultation group. Appendix B states a list of participants to these sessions.

Design preconditions 2020-2029

- Potential construction logistics centre(s) for the new construction logistics structure must be located on IJburg II. This precondition is retrieved from meetings with consultation group.
- Road transport on and around IJburg II must comply to the EURO IV standard or above (Team Luchtkwaliteit Gemeente Amsterdam, 2019).

Design preconditions 2030-2038

- Road transport on and around IJburg II must be emission-free (Team Luchtkwaliteit Gemeente Amsterdam, 2019).
- Waterborne transport around IJburg II must be emission-free (Gemeente Amsterdam, 2019a).

The preconditions for the time period 2030-2038 state that road and waterborne transport on and around IJburg II should be emission-free. This emission-free strategy from 2030 is still a policy resolution. It is unclear, whether this strategy is really being implemented and how. In addition, the term emission-free is quite vague and can include several things. What is meant by emission-free influences the design space for the construction logistics structure significantly. Therefore, three possible scenarios for emission-free transport were drafted for IJburg II from 2030, in dialogue with the consultation group. However, it should be noted that these scenarios are not fixed, as the term emission-free can be interpreted in many ways. The three scenarios were thus drawn up to give a certain direction to possible plots. The strict scenario (1), moderate scenario (2) and loose scenario (3) are stated below. Furthermore, it was determined which of the three scenarios fits the zero-emission strategy for construction logistics on IJburg II best. This was also done in dialogue with the consultation group.

- **Strict scenario**: All emissions emitted by construction logistics movements are prohibited. This means that CO_2-emissions, NO_x-emissions and PM_x-emissions are not allowed on IJburg II. This would imply that construction logistics with tyres is not longer possible because tyres account for around 50% of the PM_x-emissions (Otten et al., 2017).
- **Moderate scenario**: The prohibition of tyres for construction logistics purposes is evaluated as too strict and not feasible. Therefore, the PM_x-emissions caused by tyres are tolerated on IJburg II. However, these PM_x-emissions should be minimized as much as possible. The CO_2-, NO_x- and PM_x-emissions caused by fossil fueled engines are still not allowed.
- **Loose scenario**: The emission-free policy resolution for IJburg II from 2030 is postponed or cancelled. This means that the construction logistics structure should not comply to the emission-free standards from 2030.

The three scenarios were discussed with the consultation group. What came forward was that the Municipality of Amsterdam highly values the emission-free strategy in 2030. As a result, scenario 3 will not be plausible. However, the most strict explanation of emission-free, scenario 1, was also considered as unlikely. This because a prohibition of tyres would require a large investment and change in the infrastructure of IJburg II. Therefore, scenario 2 is seen as the most plausible situation which is why the thesis continues with this scenario.

4.2 Need to haves

The need to haves of the construction logistics structure for IJburg II can be seen in table 3. A total of nine need to haves and four sub need to haves were listed for the logistics structure. First, the requirement is stated and subsequently followed by an underpinning. This underpinning specifies why this requirement was perceived as a need to have. The underpinning box also indicates where the information can be found upon which the requirement was based. The asterisk in the table represents that this requirement should be tested quantitatively with the calculation model.

Table 3: Need to haves construction logistics structure

	Need to haves (constraints)	Underpinning
1.	**The construction logistics structure should be able to transport construction materials for residential and non-residential development from the supplier or wholesaler to IJburg II.**	All the construction material flows identified in subsection 3.4 should be transported by the construction logistics structure.
1a.	**The construction logistics structure should be able to transport heavy and large construction elements.**	The industrialization of the construction process leads to more transport of heavy and large construction elements (subsection 3.3.2).
2.	**The construction logistics structure must guarantee on-time construction material deliveries.**	All the construction material flows identified in subsection 3.4 should be delivered on-time by the construction logistics structure.
2a.	**The construction logistics structure must be able to deliver non time-critical construction materials one day after call-off.**	Storage on the construction site should be minimized which means that necessary construction materials should be delivered each day (subsection 3.3.2).
2b.	**The construction logistics structure must be able to deliver time-critical rush orders within a day.**	Time-critical rush orders should be delivered within a day to avoid delays in the construction process (subsection 1.1.2).
2c.	**The construction logistics structure must be able to transport ready-mixed concrete to the construction site within three hours.**	Ready-mixed concrete will cure within a few hours. The ready-mixed concrete should be at the construction site before this happens (subsection 3.4).
3.	**The construction logistics structure must be able to distribute construction materials for residential and non-residential development on IJburg II.**	Last-mile deliveries are necessary to reach the various construction sites on IJburg II (subsection 3.2.1).
4.	**The construction logistics structure must be able to collect, transport and store waste flows on IJburg II.**	The circular ambitions of the municipality of Amsterdam will only be met if waste materials are stored for re-use (subsection 3.3.1).
5.	**The construction logistics structure must be able to serve the residential and non-residential construction activities of IJburg II from 2020 until 2038.**	The supply of construction materials for residential and non-residential construction works on IJburg II will take place from 2020 until 2038 (subsection 3.2.1).
6.*	**The construction logistics structure must reduce CO_2-emissions due to construction logistics movements with at least 25% compared to the conventional logistics structure.**	The Municipality of Amsterdam requires a 25% reduction of CO2-emissions caused by construction logistics for IJburg II (Kuiper, 2020) (subsection 3.5).
7.*	**The construction logistics structure must reduce NO_x-emissions compared to the conventional construction logistics structure with at least 1%.**	Reduction of NO_x-emissions necessary to achieve ambitions air quality (Team Luchtkwaliteit Gemeente Amsterdam, 2019) (subsection 3.5).
8.*	**The construction logistics structure must reduce PMx-emissions compared to the conventional construction logistics structure with at least 1%.**	Reduction of PMx-emissions necessary to achieve ambitions air quality (Team Luchtkwaliteit Gemeente Amsterdam, 2019) (subsection 3.5).
9.	**The construction logistics structure must not severely damage the construction materials.**	Severely damaged construction materials lead to delays in the construction process (subsection 1.1.3).

4.3 Nice to haves

The nice to haves of the construction logistics structure for IJburg II can be seen in table 4. A total of six nice to haves are drafted for the logistics structure. First, the requirement is stated and subsequently followed by an underpinning. This underpinning explains why this requirement was perceived as a nice to have. The explanation box also specifies where the information can be found upon which the requirement was based. The asterisk in the table represents that this requirement should be tested quantitatively with the calculation model.

Table 4: Nice to haves construction logistics structure

	Nice to haves (objectives)	Underpinning
1.	**The construction logistics structure should be able to transport construction materials for residential and non-residential development by water.**	The Municipality of Amsterdam tries to increase the percentage of waterborne freight transport (Gemeente Amsterdam: Verkeer en Openbare Ruimte, 2020) (subsection 3.5).
2.	**The construction logistics structure should be low in visual and noise hindrance for current and future inhabitants.**	Noise and visual hindrance due to construction logistics should be kept as low as possible for a livable city (subsection 3.3.2).
3.	**The construction logistics structure should be able to serve the logistics structure for IJburg II to supply freight and dispose waste after 2038.**	The new urban area of IJburg II needs a logistics system after the construction activities. If the construction logistics structure can be used for this, that would be a plus (subsection 3.5).
4.*	**The construction logistics structure should decrease the road congestion compared to the conventional construction logistics structure.**	The Municipality of Amsterdam tries to decrease the road congestion in and around Amsterdam (Gemeente Amsterdam: Verkeer en Openbare Ruimte, 2020) (subsection 3.5).
5.*	**The construction logistics structure should increase the traffic safety on IJburg II compared to the conventional construction logistics structure.**	Increase in traffic safety is highly valuated by Municipality of Amsterdam (Gemeente Amsterdam: Verkeer en Openbare Ruimte, 2020) (subsection 3.5).
6.	**The construction logistics structure should minimize the hinder to construction activities.**	The infrastructure necessary for the construction logistics structure should not obstruct construction activities (subsection 3.2.1).

4.4 Sub-conclusion

From this section can be concluded that the preconditions that limit the design space for the construction logistics structure changes in 2030 due the emission-free strategy for transport vehicles on IJburg II. The requirements of the new construction logistics structure for IJburg II can be divided in need to haves (constraints) and nice to haves (objectives). A total of nine need to haves (and 4 sub need to haves) and 6 nice to haves were identified and defined.

5 Design Construction Logistics Structures IJburg II

The goal of the section is *to design conceptual construction logistics structures for IJburg II.*. In this section, the conventional construction logistics structure is explained first. Changes to the conventional structure create new construction logistics structures. Second, the design generation for subsystems of the construction logistics structure is described. Lastly, the development of three construction logistics structures out of the various subsystems designs is explained.

5.1 Conventional Construction logistics structure

This subsection elaborates upon the conventional construction logistics structure. This is defined as the construction logistics structure for IJburg II that would be used for the supply and disposal of construction materials if no changes are made. The conventional logistics structure is depicted in figure 9 by means of process flow diagrams for all the six generic construction material flows. These generic flows can be seen as subsystems for the construction logistics structure. The meaning of the symbols used in the process flow diagrams are stated in appendix D. The conventional structure is quite straight-forward because no logistics centre or other forms of collaboration between stakeholders take place. The structures per subsystem are briefly explained below figure 9.

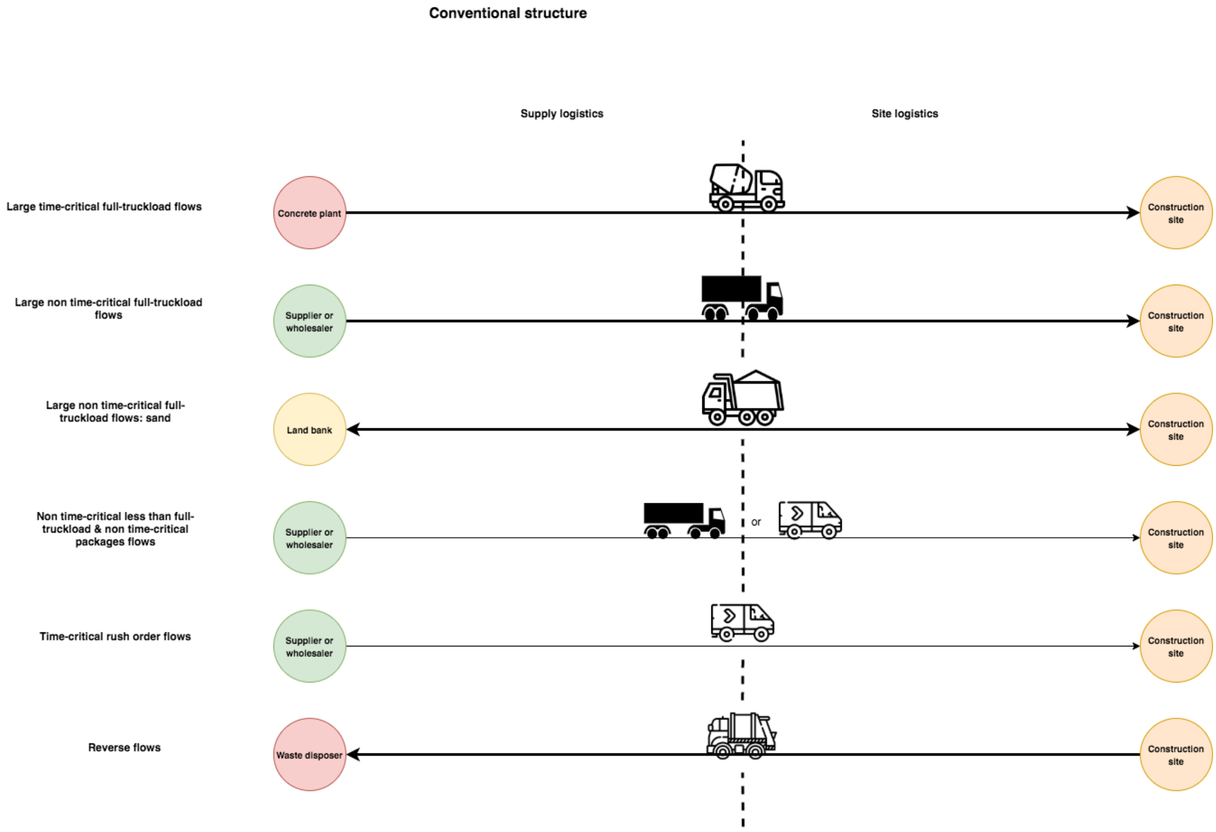

Figure 9: Schematic representation of conventional construction logistics structure IJburg II

1. **Large time-critical full-truckload flows:** Ready-mixed concrete is directly transported from the concrete plant to the construction site by a concrete truck
2. **Large non time-critical full-truckload flows:** These construction material flows are transported in heavy trucks directly from the supplier or wholesaler to the construction site. There is no collaboration between suppliers, wholesalers or freight carriers.
3. **Non time-critical full-truckload flows - sand:** The excavated sand is disposed from IJburg II to a land bank in the preparation construction site phase through a kipper, a truck used for the transport of sand. Sand required in later construction phases are also transported in a kipper from the land bank back to the construction site.
4. **Non time-critical small less than truckload & non time-critical packages flows:** These construction material flows are transported from the supplier or wholesaler to the construction site by van or truck. Which type of vehicle is used depends on the type of cargo.
5. **Time-critical rush order flows:** The small time-critical construction materials are transported from the supplier or wholesaler to the construction site, most of the time by van.
6. **Reverse flows:** Reverse flows are transported from the construction site to a waste disposer by means of a waste truck. Important to mention, there is a large variety in flows in this category as it is used as a collection group for all reverse flows. Therefore, the waste truck can differ in size depending on the waste characteristics. In figure 9, a general icon is used for waste trucks, but it is good to understand that in real life this waste truck occurs in multiple sizes.

5.2 Design synthesis

Design synthesis is the activity by which concepts are generated based on the system requirements (Leonard, 1999). This is a creative process developing designs within the design space. In this subsection, new designs are generated for the six general construction material flows described in section 5.1. First, construction logistics centres and new types of transport that could be applied in a new construction logistics structure for IJburg II were retrieved from literature. Second, a design synthesis was conducted to come up with construction logistics designs for each subsystem. Last, three construction logistics structures were drawn up. These logistics structures were built up using combinations of the subsystems designs identified in the design synthesis.

5.2.1 Types of construction logistics centres

Studies of De Bes et al. (2018), Quak et al. (2011) and Merrienboer (2013) identified a number of construction logistics solutions for residential and non-residential development. These construction logistics solutions were used as a basis in determining potential forms of construction logistics centres. A list of these construction logistics solutions are displayed in appendix E. Seven types of construction logistics centres that can be used in a new construction logistics structure for IJburg II were drawn up. These seven types are listed and elaborated below. In addition, it is indicated which type of a construction logistics centre is suitable for which general construction material flow (or subsystem). An overview with the construction logistics centres per general construction material flow can be found in table 5. A cross in the box indicates that the logistics centre can be used for this type of construction flow.

1. Centre for bundling at the source

This concept aims to consolidate construction materials outside the city. This can be at a supplier or wholesaler but also at other strategic positions outside the city. If there is no possibility to bundle the materials at a supplier or wholesaler a strategic located centre can be a solution. The last situation is assumed in this thesis. This centre should in this case be situated in the proximity of suppliers and wholesalers to store and bundle materials. Subsequently, these bundled goods can be transported to the construction site. Goal of this approach is to bundle less than truckload cargo's to full truckload cargo's in order to reduce the number of vehicle movements to the construction site.

A centre for bundling at the source can be redundant if suppliers cooperate in terms of transport which makes shared cargo loads possible. This concept of shared loads is often used in the infrastructure construction sector, but is still not embraced in the entire construction industry. This because of the lack of information sharing and cooperation. This problem can also be solved by contractors who only order construction materials from one supplier or wholesaler. This enables the supplier or wholesaler to bundle several orders and transport a full truckload to the construction site. To conclude, this type of construction logistics centre will thus be mainly suited for non time-critical small less than truckload flows and non-time critical packages.

2. Construction consolidation centre

A detailed explanation of the CCC can is stated in subsection 1.1.4. The CCC is good applicable for construction flows which are transported in small streams and are non time-critical. In addition, if the CCC is used as some sort of DIY-store it can also be a solution for time-critical rush orders, as construction materials are available in stock. The DIY-store would in many aspects a good option for IJburg, especially in view of the large number of private-builders on Centrumeiland. Furthermore, the DIY-store would also be useful for new IJburg residents.

3. Decoupling centre for road transport

The decoupling point is a centre where large non-time critical flows can be decoupled and temporary stored. This is similar to a cross-dock facility. At a cross-dock, transshipment between different types of transport takes place. Large vehicles with full-truckloads arrive at the cross-dock, subsequently the cargo of this vehicle is transshipped to other smaller transport types such as small electric vehicles. As is the case for a CCC, a decoupling centre can operate in several forms with or without a logistics service provider. The decoupling centre can be a good alternative for large non time-critical full-truckload flows.

4. Centre for production at the site

This type of a logistics centre focuses on the production of frequently used products near the construction site. If there is enough space at or near the construction site, basic elements and materials can be produced at the construction site. This is mainly applicable to construction materials that will be used in the beginning of the construction process and of which the raw materials are easily transported in full-truck loads. As analyzed in 3.4, it may be beneficial for IJburg II to produce ready-mixed concrete near or at the construction site. This flow is thus mainly suited for large time-critical full-truckload flows.

5. Buffer centre

The buffer centre is a location where transport vehicles or cargo can wait until it can be transported to the construction site. The big difference with a decoupling centre is that construction materials should not be stored at this centre. The materials should be transported to the construction site within an hour. By making use of disconnecting cargo or containers, the freight can be decoupled and transported on IJburg II with smaller and more sustainable transport types. The buffer centre reduces the waiting time for freight carriers on the construction site and stimulates JIT-deliveries. This construction logistics centre is most suitable for large non-time critical flows.

6. Centre for collection waste

A central collection centre for waste materials gives the opportunity for smart reverse streams. Waste and reverse flows can be consolidated at this centre and transported to the waste disposer. The waste can also be stored and used for other construction purposes in a later stadium of the construction process. This can increase the circularity of the construction process. However, this requires a lot of extra storage space. As reverse flows are generated in each stage of the construction process, this centre can be applied to any construction phase. Furthermore, transporting reverse flows by water to the waste disposer seems like a good alternative for IJburg II. However, this requires an inter-modal transshipment centre.

7. Transshipment centre for inter-modal transport

Most of the construction materials are transported by road. However, transport by water is a good alternative for road transport if the construction site is situated at or near waterways. As last-mile transport by water is not possible for IJburg II, transshipment of construction materials is necessary. This transshipment takes place at a transshipment centre for inter-modal transport. The transshipment centre allows transshipment from barges to other types of transport providing last-mile transport and vice versa. Construction materials can also be temporary stored at this centre. For inter-modal transshipment, a quay wall and transshipment equipment is required. Transport by water is not optimal for time-critical flows, because in general waterborne transport takes longer than road transport. Therefore, waterborne transport can be deployed for large non time-critical full-truckload flows. In addition, an often seen disadvantage of a modal shift from road to waterborne transport is the rise in costs due to the extra transshipment movements.

Table 5: Possible construction logistics centres per generic construction material flow

	1. Centre for bundling at the source	2. Construction consolidation centre	3. Decoupling centre for road transport	4. Centre for Production at the site	5. Buffer centre	6. Centre for Collection waste	7. Transshipment centre for intermodal-transport
Large time-critical full-truckload flows				X			
Large non time-critical full-truckload flows			X		X		X
Non time-critical small less than truckload flows	X	X					
Non time-critical packages	X	X					
Time-critical rush orders		X					
Reverse flows						X	X

Sub-conclusion

From table 5 can be derived that per generic construction material flow (subsystem) several types of construction logistics centres can change the construction logistics structure of IJburg II. However, it can also be stated that not all construction logistics centres are effective for each generic construction material flow. Therefore, it is advisable to determine the most suitable construction logistics centre(s) for each construction phase.

5.2.2 Transport modes

An important element in the construction logistics structure is the mode of transport and the corresponding vehicle types. This thesis focuses on the modes of transport by road and water. Vehicle types should supply construction materials from the supplier/wholesaler to the construction site or dispose reverse flows from the construction site to the waste disposer. This transport can be conducted with one mode of transport (uni-modal) or with multiple transport modes (multi-modal). In multi-modal transport, transshipment should be taken into account. Transshipment can also be necessary between different vehicle types of the same transport mode. Transport modes greatly contribute to the negative effects on the urban environment of the construction logistics structure. Therefore, an analysis was performed to potential new technologies for transport modes that can be used in the new construction logistics structure. The current technological and environmental performance of several sustainable vehicle types used for transporting construction materials were evaluated. In addition, it was examined whether this performance corresponds to the future requirements and ambitions of the Municipality of Amsterdam in the field of construction logistics.

Construction materials for IJburg II can be supplied and disposed by road or water. That is why, only transport types for road and waterborne transport are discussed. A division was made in three transport categories: road transport (transport between supplier/wholesaler and construction site, or vice versa), waterborne transport and last-mile transport (transport on IJburg II). The most relevant information for this thesis about transport modes and vehicle types is summarized in this subsection. A more extensive description of road and waterborne transport for construction materials is included in appendix F.

Road transport

Transport of construction materials by road can be performed by different vehicle types. The most suitable transport type depends on the type of cargo. A number of road transport types for construction materials are: (1) kipper for the transportation of sand; (2) concrete truck; (3) heavy truck; (4) light truck; (5) van; and (6) waste truck. The fuel technology of trucks and vans is quickly evolving over time. However, most of the trucks and vans are still powered by diesel engines. The Municipality of Amsterdam aims to be emission-free which means that the diesel powered vehicles should be replaced. There are two important technologies that, in the long run, can ensure emission-free road transport: electric and hydrogen-powered trucks (Jorritsma, 2018). However, there is still a long way to go before these two technologies can replace diesel completely.

Electric vans and trucks

Electric vehicles are powered by an electric engine that draw energy from an on-board battery or a fuel cell. The power can also be drawn from an external electric energy supply system (overhead wire). Electric driving is growing in the light truck and vans segment. Currently, these types of vehicles are mainly used for urban or urban regional transport for so called last-mile deliveries. The average range of the light electric trucks is about 300 kilometres (Jorritsma, 2018). Bearing in mind that more than 80% of the road freight transport journeys are of distances below the 80 kilometers (Kok et al., 2017), there is a huge potential to deploy light electric trucks for this purpose. However, the first electric trucks cannot be used for transporting heavy construction materials. These light electric trucks are currently deployed for waste disposal and urban logistics because they have a gross weight of 27.000 kg (Seijlhouwer, 2019). Electric vans are already driving around the inner cities in larger numbers.

At the moment, these vans are not suited for transporting heavy construction materials and are therefore used for transport of personnel and packages.

Electric medium and heavy sized trucks with a long range are not available yet, these are still being developed. Some concepts have been introduced but it seems that electric trucks in this segment will take some time before they are operational (Dijkhuizen, 2020). However, for short distances and last-mile deliveries, small electric tow trucks are available that can transport heavy construction materials a few kilometres. This can be a solution for heavy last-mile deliveries on IJburg II. This indicates that the biggest problem for the implementation of electric trucks in the construction logistics structure is the disability to not be able to carry heavy construction materials over longer distances.

Hydrogen-powered trucks

Hydrogen can be used as fuel for a special type of combustion engine or in a battery that powers an electric engine. The electricity for the electric engine is delivered by a fuel cell in which hydrogen reacts with oxygen to produce electricity. Just like the electric heavy trucks, the hydrogen trucks are still in development. The availability of solid infrastructure to refuel hydrogen powered vehicles is a point of concern (Jorritsma, 2018). At the moment, there are only five locations where hydrogen can be refueled. This makes the implementation of hydrogen powered truck in the construction logistics structure for IJburg II highly unlikely.

Vessels

Construction materials by water are mainly transported in push barges or ponton barges (van Rijn et al., 2020). These types of ships are attractive because of the high load capacity and the possibility to combine barges. These factors could lead to economies of scale (Macharis et al., 2011). In the Netherlands, barges are available in different sizes and are propelled by so called pushers (de Leeuw van Weenen et al., 2018). The conventional pusher is equipped with a heavy diesel engine which is not sustainable. These days, research focuses on emission-free waterborne transport. Over the past few years, hybrid ships are developed with a combination of diesel and electric engines. Furthermore, the first electric vessels are now sailing in the canals of Amsterdam for construction logistics and waste disposal purposes. However, these ships are not able to transport large volumes over longer distances. That is why, the implementation of electric ships for transporting heavy construction materials over longer distances is not feasible at the moment. Waterborne transport over shorter distances with heavy materials or over longer distances with light materials is achievable.

Last-mile transport

Once arrived on IJburg II, the construction materials have not reached the final destination yet. When using a construction logistics centre on IJburg II, the materials will still have to be transported from the centre to the construction site. This last-mile transport can for example take place with small vans and (tow) trucks driving around IJburg II. As short distances have to be covered for last-mile transport, this can be done electrically. Another option would be to realize a dedicated transport system for last-mile deliveries on IJburg II such as a small railway track or conveyor belt. However, this requires extra investments on the two islands. What also should be considered is the need for transshipment in case of multi-modal transport of transport with multiple vehicle types. Therefore, transshipment equipment is explored in more detail below.

Transshipment equipment

The necessary transshipment equipment depends on the type of handled construction materials. Bulk materials should be transshipped differently than pallets. To enable transshipment from waterborne to road transport or vice versa, a quay wall is necessary, especially when large volumes of construction materials are transported. Grab cranes are mostly used for transshipment of dry bulk such as sand and gravel (Negenborn et al., 2017). Heavy construction elements should be loaded using specialized grabs, for example to carry wood or prefab elements (Schott and van den Hoed, 2017). Pallets can be handled with standard equipment such as slings and fork lift trucks. Subsequently, vans, (tow) trucks or any other last-mile transport vehicles should carry the construction materials after the transshipment from the quay wall or storage location to the construction site. In addition, most transshipment equipment is already available in electric variants.

Important to note is that electric last-mile transport and electric transshipment is only feasible if the required electric charging infrastructure on IJburg II is constructed. Otherwise, these vehicles and transshipment equipment will still be powered by electricity generated by diesel generators which is not desirable.

5.2.3 Design subsystems

The designs for the six general construction material flows (or subsystems) are elaborated below. The meaning of the symbols used in the process flow diagrams are stated in Appendix D. As sand is transported in opposite direction than all the other non time-critical full-truckload flows and is seen as an important construction logistics flow, separate designs were generated for this 'subsystem'. Moreover, the designs for non time-critical less than full truckload flows and non time-critical packages are equal on most points. Therefore, these designs are described together. Important to note is that designs were generated for two time periods: 2020-2029 and 2030-2038. This is due to the fact that the design constraint of emission-free transport significantly impacts the design space and thus the possible designs. In addition, the designs make a distinction between supply logistics (transport until IJburg II) and site logistics (transport on IJburg II).

Large time-critical full-truckload flows

The only time-critical full-truckload flow used during the construction activities for IJburg II is ready-mixed concrete. Therefore, designs are generated for this construction material flow. The designs are depicted in figure 10 and are explained below into more detail per time period.

Designs 2020-2029

1. This design includes a centre for construction at the site. Minerals for concrete production are shipped per fossil fueled barge to a concrete plant on IJburg II. This concrete plant should have a quay wall to enable transshipment of minerals. In this way, ready-mixed concrete is produced at or near the construction site. The ready-mixed concrete can be last-mile distributed from the concrete plant to the construction site by means of a piping system or small concrete trucks.

Designs 2030-2038

1. This design is almost the same as described in design 1 for the time period 2020-2029. However, there is one big difference. A quay wall is added to the logistics structure to enable emission-free deliveries of minerals for the production of concrete. This quay wall is required to exchange a fossil fueled pusher for an emission-free pusher and should be located just outside the emission-free zone. The quay wall is necessary because it is not expected that many emission-free pusher are available in 2030. Let alone that these emission-free pushers can bridge long distances with heavy construction materials.

2. This logistics design directly transports ready-mixed concrete from the concrete plant to the construction site. The concrete is transported by an emission-free electric truck. This should be technologically possible because a number of concrete plants are located within a radius of 25 kilometre around IJburg II.

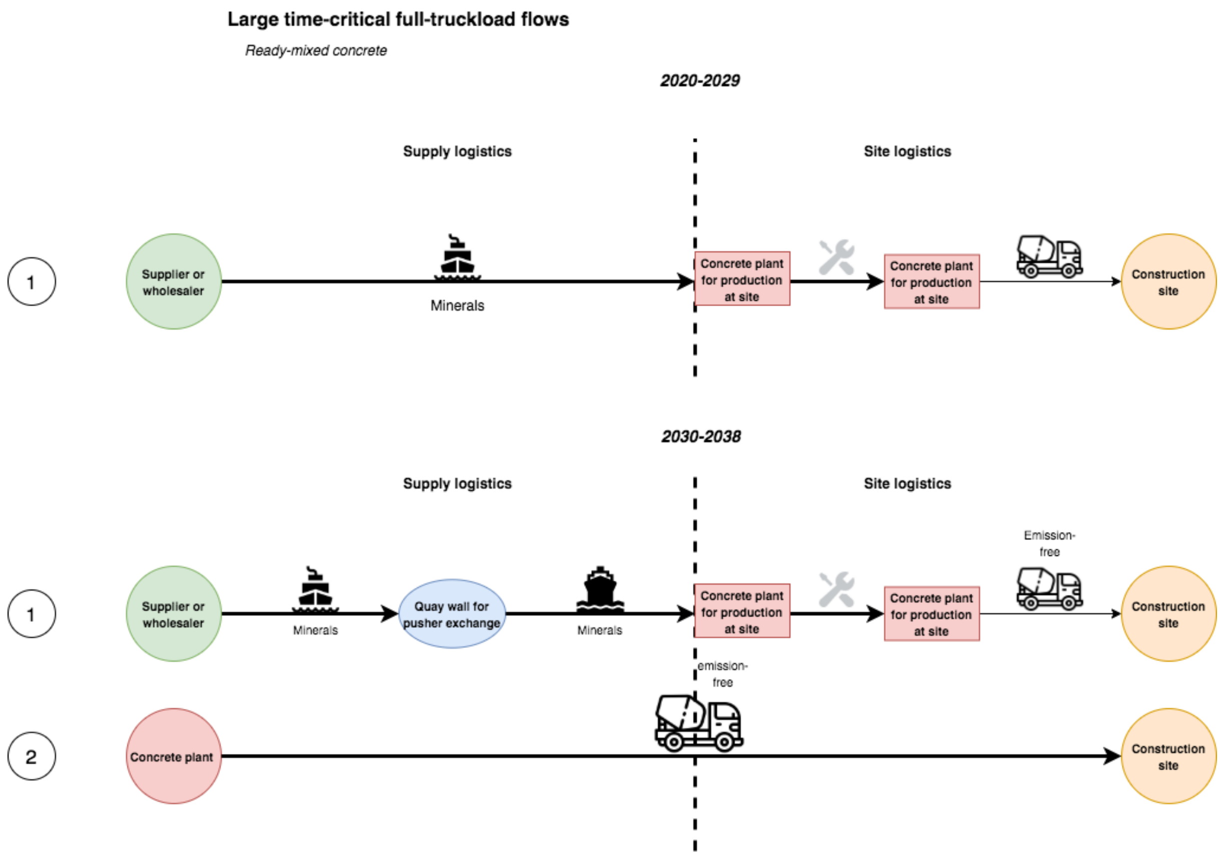

Figure 10: Designs for large time-critical full-truckload flows

Large non time-critical full-truckload flows

The generated designs for non time-critical full-truckload flows can be found in figure 11.

Designs 2020-2029

1. This logistics design for transporting non time-critical full-truckload flows makes use of a decoupling centre for road transport. Heavy trucks transport construction materials to IJburg II. At IJburg II, the cargo of these heavy trucks are decoupled at the decoupling centre and temporary stored. Last-mile deliveries are performed from the decoupling centre by means of a milk-round with a small truck or van, by a conveyor belt or by a distribution system on rails.

2. In this design, the construction materials are transported by water with a push barge. The barge moors at the transshipment centre for inter-modal transport where the construction materials are transshipped and if necessary temporary stored. The construction materials should be distributed from the transshipment centre to the several construction sites. This is done by means of a milk-round with a small truck or van, conveyor belt or distribution system on rails.

3. This design incorporates a buffer centre in the construction logistics structure. Heavy trucks arrive at IJburg II. If the construction materials cannot be delivered at the construction site, the trucks are sent to the buffer centre. Here, cargo is decoupled from the truck and subsequently transported to the construction site with a tow truck if the construction site is available again.

Designs 2030-2038

1. This design makes also use of a decoupling centre for road transport just as design 1 of the time period 2020-2029. However, the decoupling point is not on IJburg II, but somewhere just outside the emission-free zone. This is necessary, because not all heavy trucks will be emission-free from 2030. Transport from the decoupling centre can take place by emission-free alternatives such as an emission-free truck, trolleys on rails or an electric tow truck.

2. The construction materials are in this structure transported by consecutively a diesel fueled push barge and an emission-free barge. The pusher is swapped at a quay wall just outside the emission-free zone. The emission-free barge subsequently moors at the inter-modal transshipment centre, from where the construction materials are distributed emission-free across IJburg II.

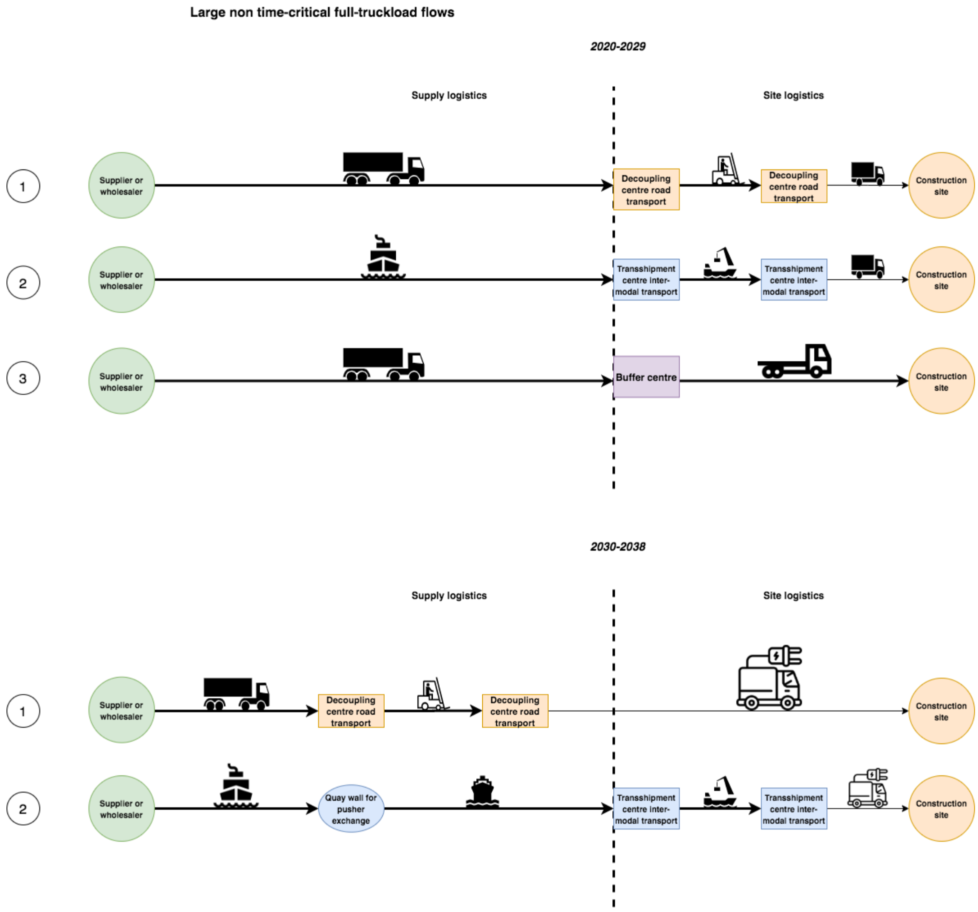

Figure 11: Designs for large non time-critical full-truckload flows

Large non time-critical full-truckload flows: sand

Sand is a construction flow that first should be carried away from the construction site during the site preparation phase due to excavation activities. The amount of sand to be removed during excavation works is considerable. However, sand should be transported back to the construction site during the substructure and shell construction phase which is an exception to other material flows. Therefore, designs were generated for the material flows of sand. The designs are illustrated in figure 12

Designs 2020-2029

1. Sand is transported from the construction site to a centre where reverse flows are stored and transshipped to waterborne transport. This is a combination of a centre for waste collection and a centre for inter-modal transport. The transport on IJburg II is executed via a conveyor belt, small truck or a truck destined for sand transport (kipper). Sand can be (temporary) stored at this facility before it is transshipped to a barge. Subsequently, the barge carries the sand to the land bank near IJburg II. This land bank is planned at Buiteneiland. When sand is necessary in the construction process, the sand is reclaimed from the land bank. Transport to the construction site takes place in the same way as it was transported to the land bank. Another possibility is to store a small amount of sand at the centre for waste collection. This sand can be used in later stages of the construction process. However, this requires extra storage space at IJburg II but will decrease the trips to the land bank.

2. In this design, sand is transported from the construction site to the centre for collection waste by means of a conveyor belt, small truck or kipper. Sand is temporary stored at this centre before it is transported to the land bank through a kipper. This design allows high load factors of kippers transporting sand from IJburg to the land bank.

3. This logistics design is almost similar to design 1. However, the sand is not shipped by barge to the land bank but to a nearby concrete plant. The concrete plant makes concrete destined for the construction activities on IJburg II. This results in some sort of circular concrete which is in line with the ambitions of the Municipality of Amsterdam.

Designs 2030-2038

1. This logistics design transports sand between the construction site and collection centre for waste by means of an emission-free conveyor belt or emission-free trucks/kippers. Just as is the case in the first design of 2020-2029, sand is shipped to the nearby land bank. However, since emission-free waterborne transport is required, this is done via an emission-free push barge.

2. In this structure, sand is collected through emission-free transport such as emission-free kippers, conveyor belt or rail system. Subsequently, the sand is brought to the centre for collection of waste. Thereafter, sand is transported to the land bank emission-free by a kipper. It is expected that, by that time, a heavy-loaded kipper is feasible to drive a small distance emission-free.

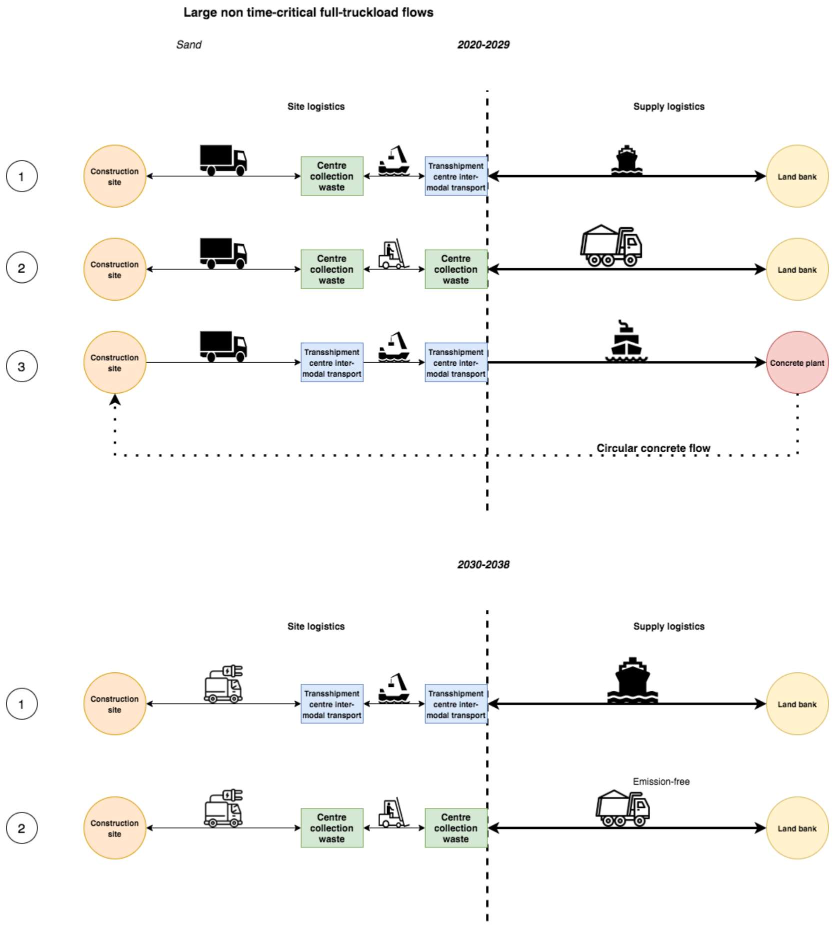

Figure 12: Designs for sand flows

Non time-critical small less than truckload & non time-critical packages flows

Since the designs for the subsystems non time-critical small less than truckload flows and non time-critical packages are almost similar, the sub-designs are elaborated in once. The only difference is the size of the vehicles. For less than full-truckload flows these are mainly trucks and for the packages vans. The construction logistics designs for these subsystems are displayed in figure 13.

Designs 2020-2029

1. The first design includes the construction consolidation centre. Construction materials are delivered by a truck or van to the CCC on IJburg II. The construction materials are consolidated at the CCC and temporary stored. If the construction materials are necessary on the construction site, these are delivered JIT. The last-mile distribution on IJburg II takes place with a small truck or van driving a milk round, a rail system or a conveyor belt.

2. In this structure, construction materials are transported via a centre for bundling at the source. The materials are consolidated at a strategically chosen point close to many suppliers and wholesalers. From this centre, full-truckload flows are sent to the construction site by van or truck. The materials are delivered at several sites on IJburg II via a milk-round.

Designs 2030-2038

1. This design is almost the same as design 1 for the period 2020-2029. However, the CCC is situated outside the emission-free zone to enable deliveries of fossil fueled vehicles to the CCC. From the CCC, the construction materials are transported emission-free and JIT to the construction site. This transport is performed with emission-free vehicles or a rail system.

2. This design is similar to design 2 for the period 2020-2029. Transportation to the construction site is however conducted with emission-free trucks and vans. As large trucks will not be available in large numbers as of 2030 and later, smaller deliveries with emission-free vehicles are inevitable. Unless the Municipality of Amsterdam facilitates a number of large emission-free trucks to perform these transports between the centre for bundling at the source and the construction site.

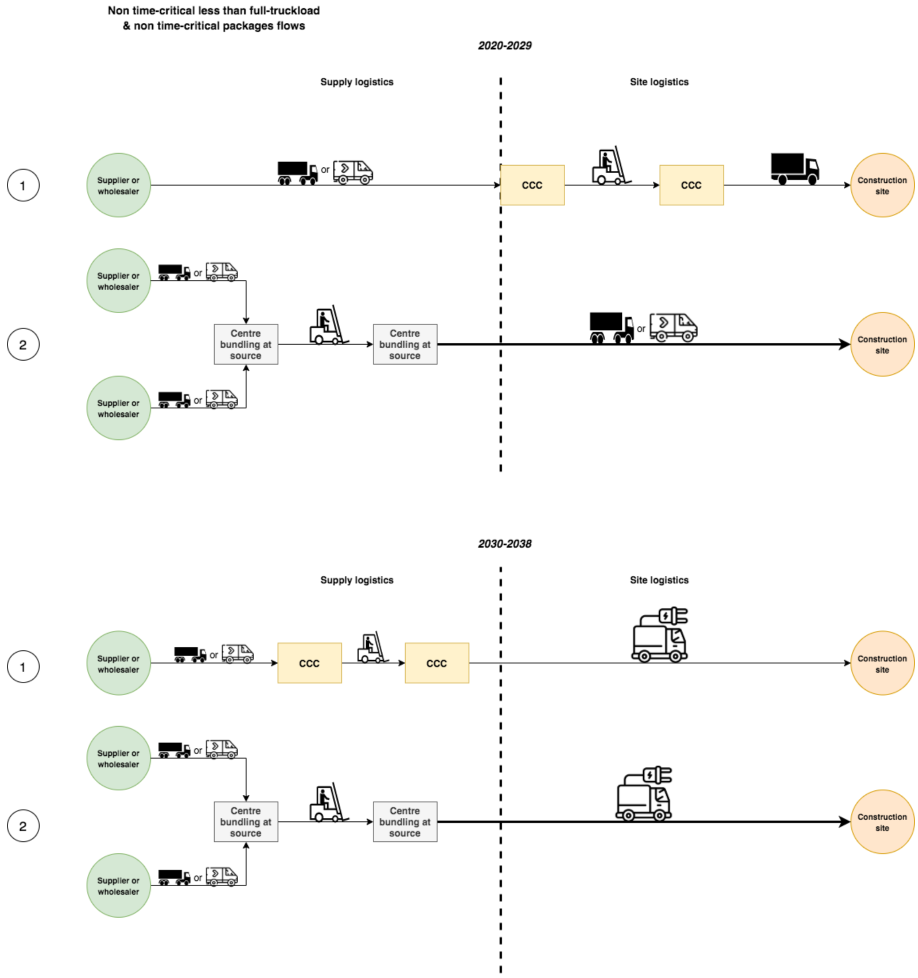

Figure 13: Designs for non time-critical small less than truckload & non time-critical packages flows

Time-critical rush order flows

The designs for the time-critical rush order flows are displayed in figure 14.

Designs 2020-2029

1. The rush orders are delivered at the construction consolidation centre by van. From here on, the packages can be sent to the construction site by milk-round, conveyor belt or rail system. Since the materials are time-critical, this should be done immediately. A CCC in the form of a DIY-shop would make direct shipment to the construction site possible, if the product is in stock.

Designs 2030-2038

1. The packages are brought to a CCC just outside the emission-free zone by (fossil fueled) van. From here on, the packages are brought to the construction site by emission-free van, rail system or conveyor belt.

2. This logistics design directly transports the rush orders from the supplier or wholesaler to the construction site. The rush orders are transported by an emission-free van. This should be technologically feasible because in 2030 vans are able to carry light construction materials emission-free over longer distances.

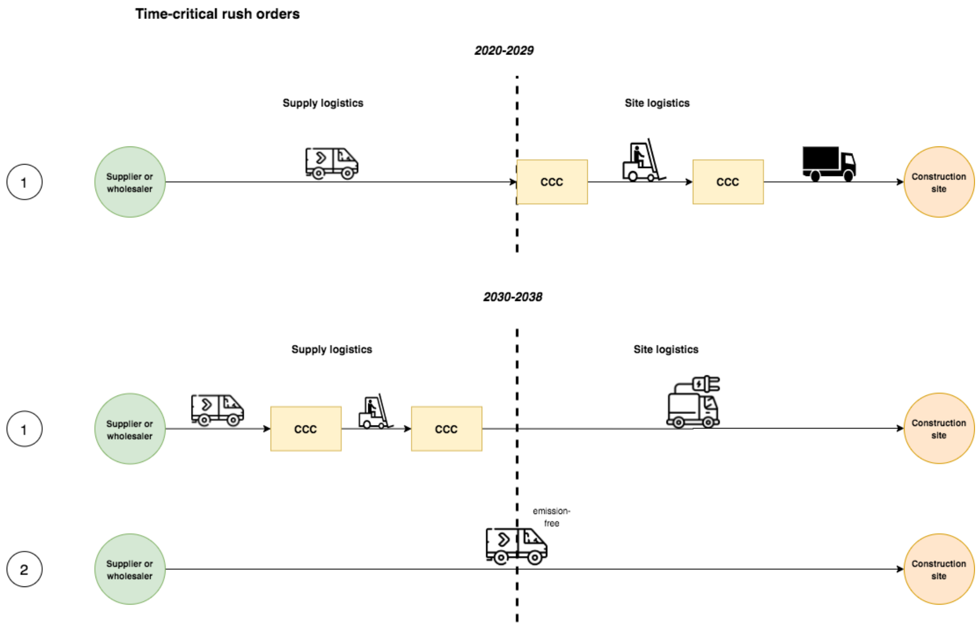

Figure 14: Designs for time-critical rush order flows

Reverse flows

Reverse flows take the opposite direction from construction materials: from construction site to waste disposer. The designs for reverse flows can be found in figure 15.

Designs 2020-2029

1. This construction logistics design includes a centre for waste collection in combination with a transshipment centre for inter-modal transport. The waste materials are collected on IJburg II and transported to the centre for waste collection by means of a milk-round with a waste truck, a conveyor belt or rail system. Materials that should be re-used on the islands, are stored at the collection point. The waste flows are transshipped at the transshipment centre to barges and from there on transported to the waste disposer. Therefore, it would be useful to situate the collection centre for waste near the transshipment facility on IJburg II to avoid extra transport movements.

2. The reverse materials are collected at construction sites by a milkround, conveyor belt or rail system on IJburg II and brought to a centre for waste collection. Potential circular materials are stored at this centre. The waste flows are transshipped to a waste truck and are subsequently brought to the waste disposer.

Designs 2030-2038

1. This design looks almost like design 1 for the period 2020-2029 but has two adjustments. First, the collection of waste on IJburg II is performed with emission-free waste trucks, a conveyor belt or a rail system. Second, waste is picked up by an emission-free barge at IJburg II. Depending on the distance to the waste disposer, the pusher for the barge should be swapped from an emission-free pusher to a fossil fueled pusher at a quay wall just outside the emission-free zone. However, it is expected that a quay wall is not necessary, as the waste disposer is probably not further than 20 kilometres away from IJburg II.

2. This logistics design is almost equal to design 2 for the period 2020-2029. However, reverse flows are collected emission-free on IJburg II and the transport from the centre for collection waste to the waste disposer is performed with emission-free waste trucks.

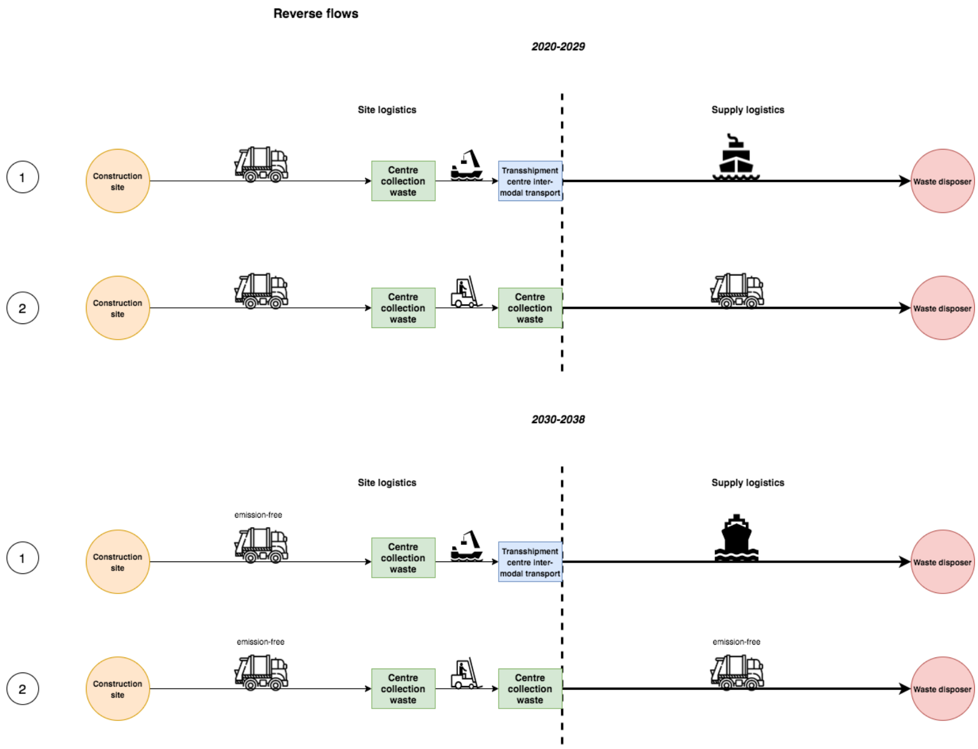

Figure 15: Designs for reverse flows

5.3 Designs Construction logistics structures

In this subsection, three construction logistics structures are developed for IJburg II making use of the new subsystem designs drawn up in subsection 5.2.3 and the subsystem designs of the conventional logistics structure in subsection 5.1. The new designs display new construction logistics structures for subsystems using construction logistics centres and new vehicle types.

Option menu construction logistics centres

As was concluded in subsection 5.2, not every construction logistics centre is suitable for every construction material flow. Therefore, it is advisable to look at construction logistics centres per construction phase to ensure that the change in the construction logistics structure is effective. Based on the table 2 in subsection 3.4 and table 5 in subsection 5.2.1, suitable construction logistics centres per construction phase were determined. An overview of the logistics centre per construction phase is displayed in table 6. A cross in the box indicates that the logistics centre can be used in that particular construction phase. The first three construction phases are largely dominated by large full-truckload flows (time-critical or non time-critical) and reverse flows. As a result, construction logistics centres that change the structure of these three subsystems are obvious for the first three construction phases. This means, among others, construction logistics centres for decoupling road transport, for collection waste and for inter-modal transport. The final construction phase is mainly characterized by smaller construction material flows and again reverse flows. Effective logistics centres in that phase are a centre for bundling at the source, a CCC or a collection point for waste. This implies that table 6 could therefore be used as a kind of option menu for choosing construction logistics centres per construction phase.

Table 6: Option menu construction logistics centres

	1. Centre for bundling at the source	2. Construction consolidation centre	3. Decoupling centre for road transport	4. Centre for Production at the site	5. Buffer centre	6. Centre for Collection waste	7. Transshipment centre for inter-modal transport
Preparation construction site						x	x
Substructure construction			x	x	x	x	x
Shell construction			x	x	x	x	x
Final construction	x	x				x	

Composing three new construction logistics structures

The three new construction logistics structures were composed making use of the new subsystem designs from subsection 5.2.3 and subsystem designs from subsection 5.1. However, before the construction logistics structures could be compiled, it needed to be decided which construction logistics centres were to be used in the new structures. Based on table 6, combinations were made of construction logistics centres for each new structure. In doing so, it was attempted to use each construction logistics centre at least once in one of the three structures. Important to note is that many more combinations of construction logistics centres and thus combinations of subsystem designs are possible. This thesis only designed three new logistics structures due to time limitations but many more structures can be made.

The three designs of the construction logistics structure are elaborated below. First, it is stated which construction logistics centres are used in that design. Second, it is indicated which design for a subsystem hereby applies. The structure of a subsystem changes from the conventional structure to the new structure if the implemented construction logistic centre is effective for that subsystem, unless explicitly stated otherwise. Tables 7, 8 and 9 indicate the designs per subsystem for the two time periods. The designs are depicted in figures 16, 17 and 18. Detailed explanations of the designs are given in subsection 5.1 for the conventional logistics structure and subsection 5.2.3 for the newly generated designs. Important to note, last-mile transport in all the designs is conducted by light electric vans not by conveyor belt or rail system. This was chosen to enable calculations to the construction logistics structures.

Design 1

Implemented construction logistics centres

- Construction consolidation centre
- Centre for collection waste
- Transshipment centre for inter-modal transport

Designs of subsystem

Table 7: Designs subsystems construction logistics structure 1

	Large time-critical full-truckload flows	Large non time-critical full-truckload flows	Small less than truckload flows	Non time-critical packages	Time-critical rush orders	Reverse flows
2020-2029	Conventional structure	Design 2	Design 1	Design 1	Design 1	Design 1
2030-2038	Design 2	Design 2	Design 1	Design 1	Design 1	Design 1

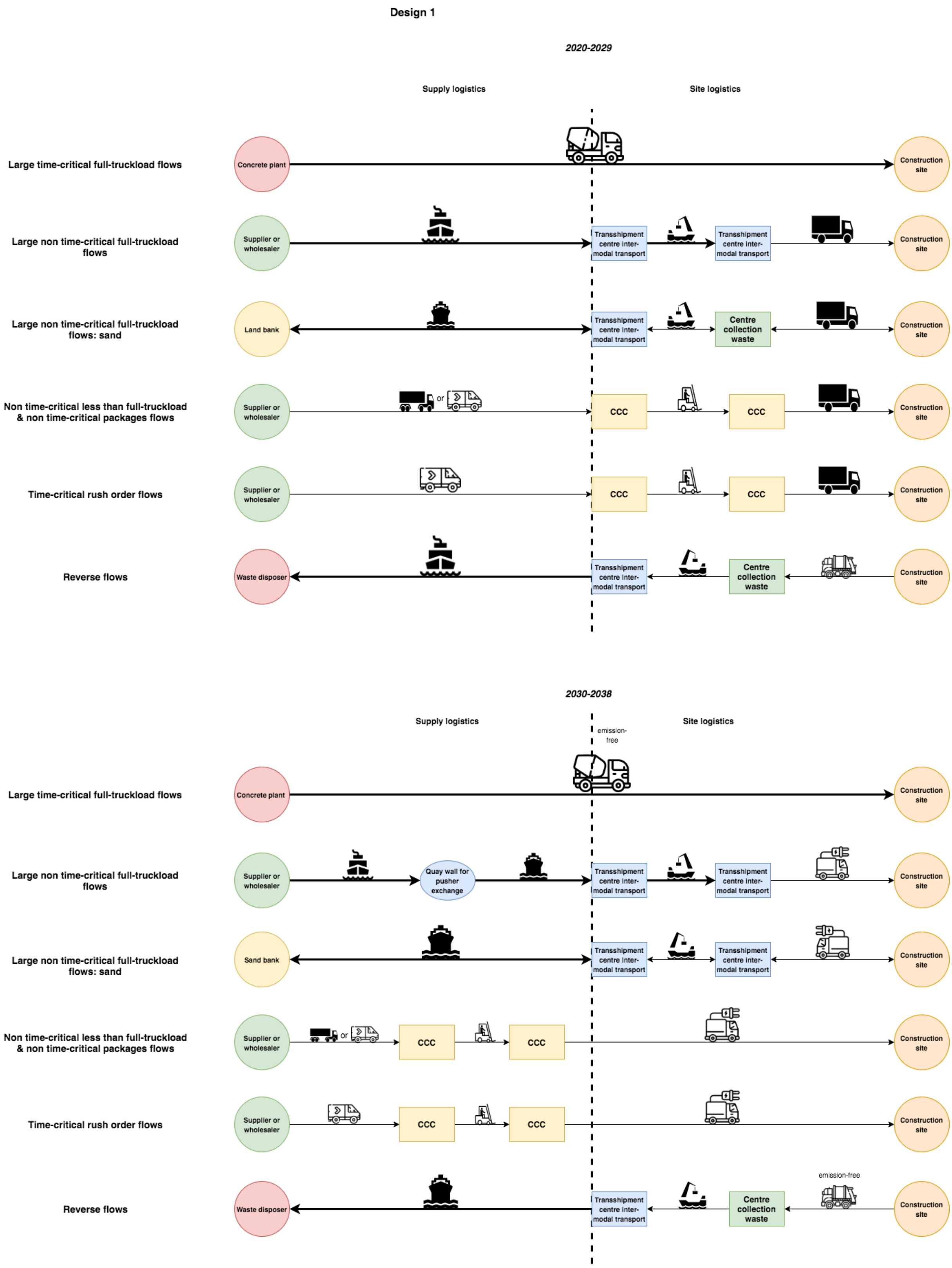

Figure 16: Design 1 construction logistics structure

Design 2

Implemented construction logistics centres

- Construction consolidation centre
- Decoupling centre for road transport (from 2030)
- Centre for production at the site
- Centre for collection waste
- Transshipment centre for inter-modal transport only for minerals, sand and waste

Designs of subsystem

Table 8: Designs subsystems construction logistics structure 2

	Large time-critical full-truckload flows	Large non time-critical full-truckload flows	Small less than truckload flows	Non time-critical packages	Time-critical rush orders	Reverse flows
2020-2029	Design 1	Conventional structure	Design 1	Design 1	Design 1	Design 1
2030-2038	Design 1	Design 1	Design 1	Design 1	Design 1	Design 1

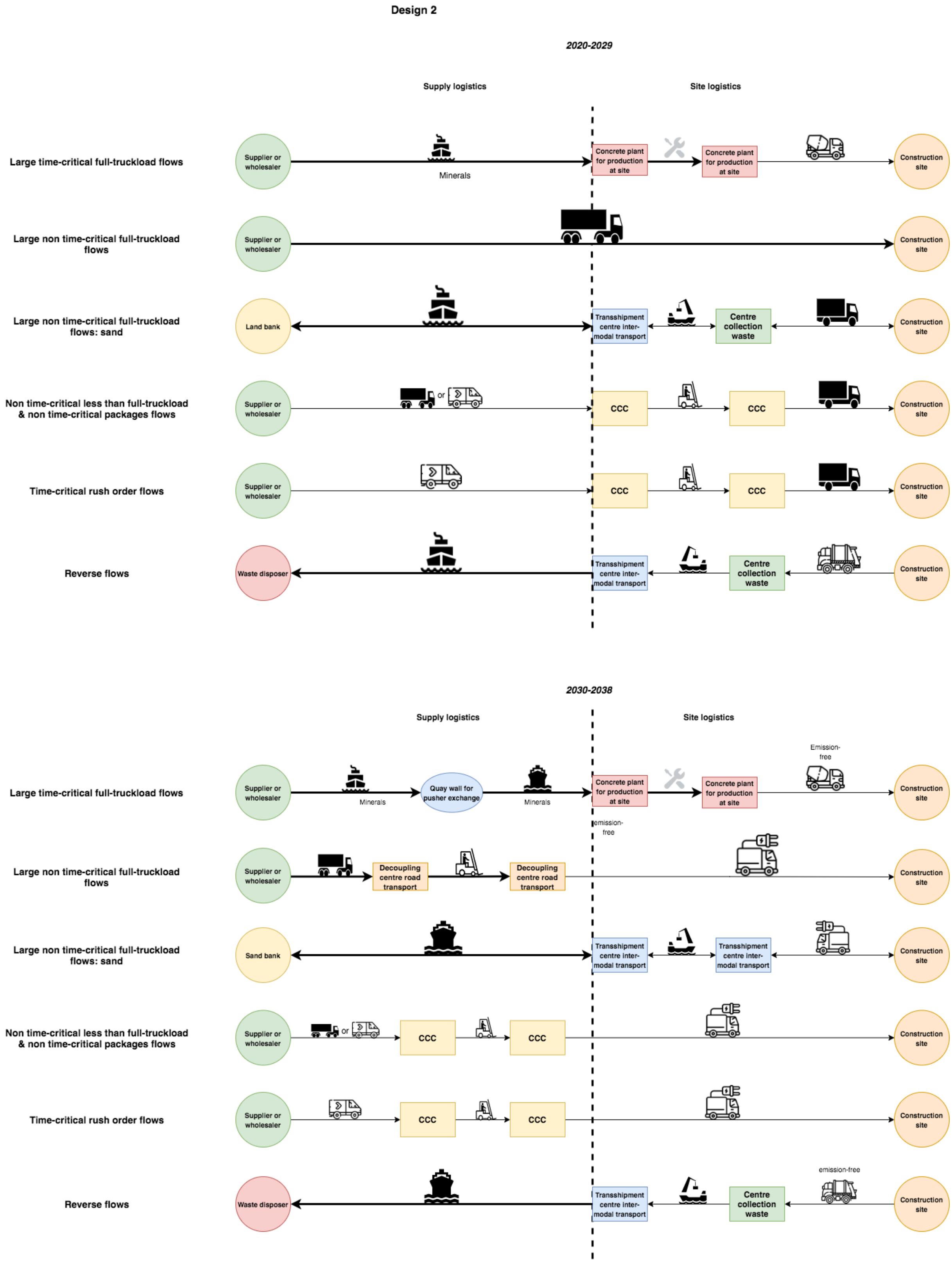

Figure 17: Design 2 construction logistics structure

Design 3

Implemented construction logistics centres

- Centre for bundling at the source
- Decoupling centre for road transport
- Centre for collection waste not used for sand

Designs of subsystem

Table 9: Designs subsystems construction logistics structure 3

	Large time-critical full-truckload flows	Large non time-critical full-truckload flows	Small less than truckload flows	Non time-critical packages	Time-critical rush orders	Reverse flows
2020-2029	Conventional structure	Design 2	Design 2	Design 2	Conventional structure	Design 2
2030-2038	Design 2	Design 2	Design 2	Design 2	Design 2	Design 2

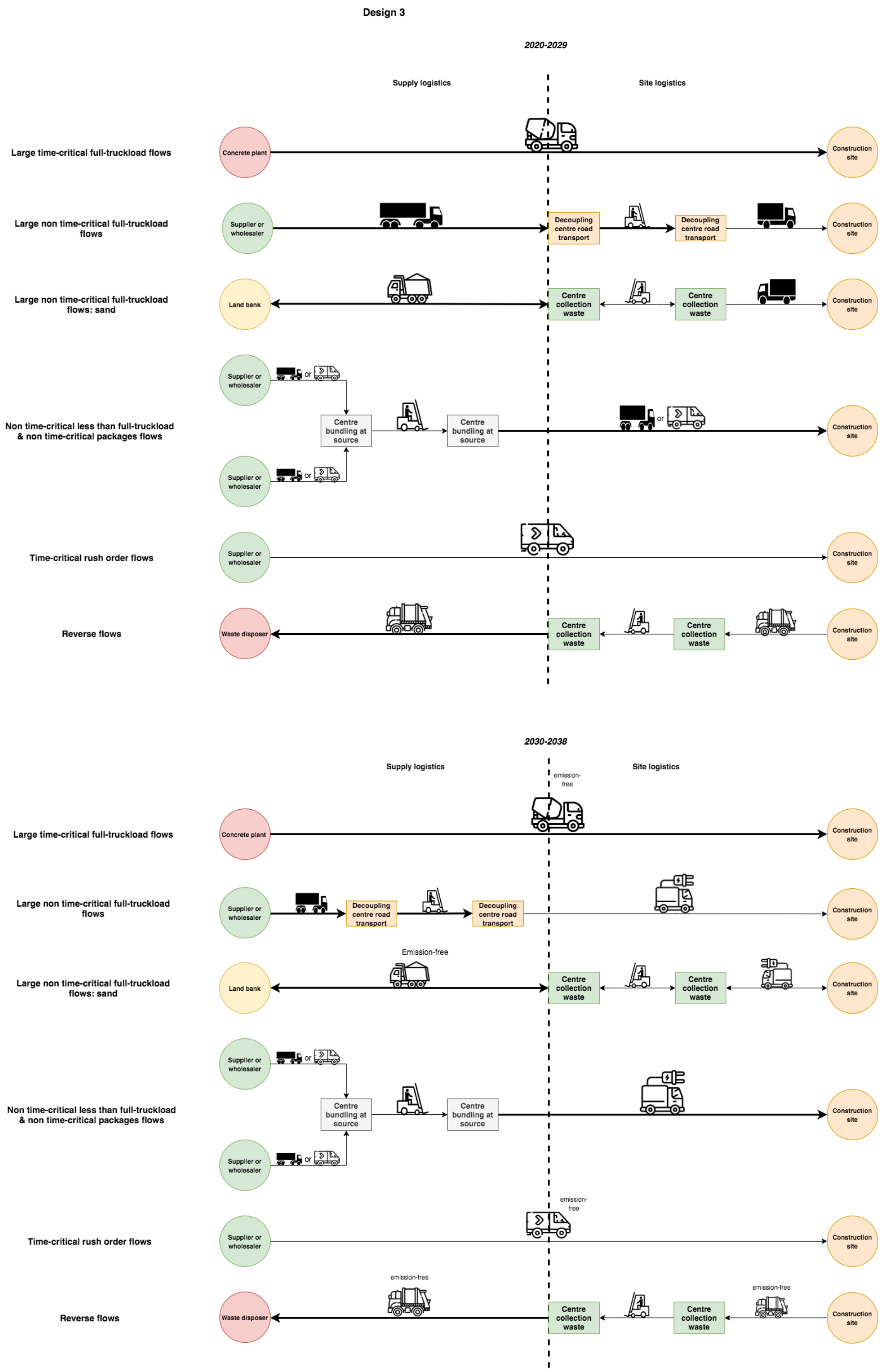

Figure 18: Design 3 construction logistics structure

5.4 Sub-conclusion

Seven types of construction logistics centres can improve the construction logistics structure for IJburg II. These seven logistics centres are: 1. centre for bunding at the source; 2. CCC; 3. decoupling centre for road transport; 4. centre for production at the site; 5. buffer centre; 6. centre for collection waste; and 7. transshipment centre for inter-modal transport. However, it can be concluded that not every type of construction logistics centre can be applied to any of the six generated construction material flows for the development of IJburg II. Therefore, table 5 in subsection 5.2.1 states which construction logistics centre can be applied for which construction material flow. From this it can also be concluded that not every construction logistics centre is applicable in every construction phase which can be seen in table 6 in subsection 5.3.

Construction materials are transported by one mode (uni-modal) or multiple modes (multi-modal). In multi-modal transport and transport with different vehicle types, transshipment should be taken into account. Transport of construction materials by road can be performed by different vehicle types. The most suitable vehicle type depends on the type of cargo. Construction materials by water are transported by push barge. Electric vehicles and vessels are on the rise for both road and waterborne transport. However, for both modes of transport, the transport of heavy construction materials over long distances is not yet feasible. Transport over shorter distances with heavy construction materials or longer distances with light construction materials is achievable. Last-mile transport of construction materials on IJburg II can be performed in different ways: conveyor belt, light truck, van or rail system. However, this thesis only assumes light electric trucks for last-mile deliveries to enable calculations to the construction logistics structure.

Three designs of construction logistics structures for IJburg II were drafted. First, designs were generated for the subsystems of the construction logistics structure. These subsystems are the generic construction material flows. The new designs of subsystems were developed with construction logistics centres and new vehicle types for construction logistics. Per subsystem, designs were made for the time period till 2030 and for the time period after 2030 due to the change in applicable preconditions. Thereafter, three construction logistics structures were composed by combining several designs of subsystems. Only three new structures for IJburg II were created due to time limitations. However, many more can be made out of this thesis.

6 Calculation Model & Design Verification

The aim of the section is *to test the conceptual construction logistics structures on the new requirements.*

In this section, the developed calculation model is discussed first. Second, the results of the is developed model are described. Last, the three construction logistics structures are tested on the drafted requirements (need to haves and nice to haves) both qualitatively and quantitatively (calculation model). The calculation model is a tool to gain insight into the scale of construction logistics movements and the CO_2-, PM_x- and NO_x-emissions caused by logistics movements. By means of this tool, it was tested if the construction logistics structures comply to the requirements in the field of CO_2-, PM_x- and NO_x-emissions. Moreover, the model indicates how many and what kind of transport movements per structure are required for the urban development project IJburg II.

6.1 Reference project

Logistics data of a reference construction project was used to predict the construction logistics movements for IJburg II. The use of a reference project was inevitable, as many types of construction materials will be transported to IJburg II. This made it difficult to determine the quantity and type of transport per construction material. Therefore, reference construction projects with available data on transport movements were examined. This was rather difficult, as logistics data on construction projects are often not publicly available or not recorded. Nevertheless, a reference construction project of 60 new build houses in the city of Zwolle was found and used. This project came closest to the urban development project of IJburg II of all available reference construction projects with data on transport movements. Not so much by the size of the project but on other project characteristics such as a construction project at the edge of the city, residential development and low construction heights. The reference construction project is part of the research of Rinsma et al. (2015) who aimed to gather logistics insights of construction projects.

Rinsma et al. (2015) listed the transport movements for the reference construction project according to vehicle type per construction phase. Hereby, it could be concluded how many times a certain vehicle type delivered to the construction site in that construction phase. Rinsma et al. (2015) made a distinction in five vehicle types: van, heavy truck, kipper, light truck and concrete truck. Moreover, the vehicle movements were listed for three types of construction methods: 1. construction activities with in-situ cast concrete; 2. construction activities with prefab elements and 3. construction activities with wooden elements. Based on the above described data and more additional data, a model was created that calculates the construction logistics movements, the CO_2-, PM_x- and NO_x-emissions of a construction logistics structure for IJburg II. Examples of additional data are: the amount of excavated soil (Post and Monen, 2019), vehicle capacities and load factors.

6.2 Description model

This subsection describes the input, calculations and output of the developed calculation model. The input were the conventional logistics structure, the three newly designed construction logistics structures elaborated in subsection 5.3 and the case-specific values for calculating the vehicle movements and emissions. The output were the vehicle movements, CO_2-, PM_x- and NO_x-emissions per construction phase. The model converts the input into the output by means of calculations. The calculations are shortly described in subsection 6.3 and depicted in detail in appendix G. The schematic representation of the model is displayed in figure 19. A number of assumptions were made for this model due to a number of uncertainties. These are illustrated and explained together with the case-specific values in Appendix H.

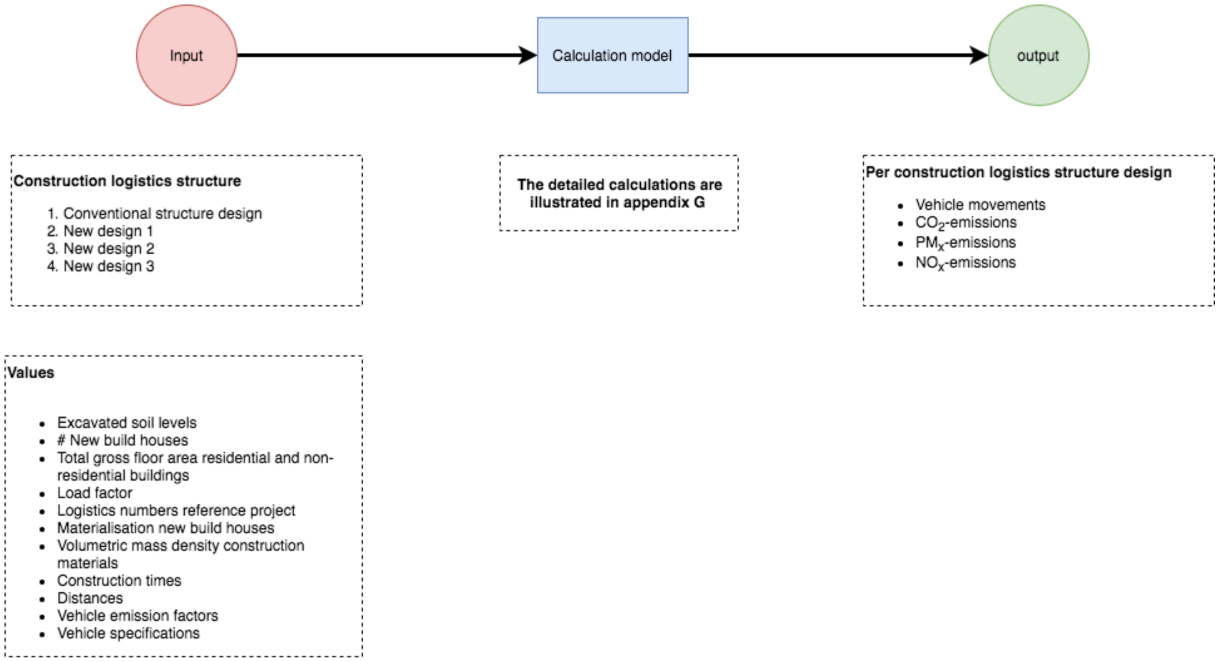

Figure 19: Schematic representation calculation model

6.3 Calculations

In this subsection, it is briefly explained what was calculated per calculation step in the model. The calculations in the developed model were divided into three steps which are listed below. The detailed calculations are illustrated in appendix G.

1. Calculations to determine the vehicle movements of the conventional construction logistics structure.

2. Calculations to convert the vehicle movements of the conventional logistics structure to vehicle movements of the new construction logistics structures.

3. Calculations to determine the CO_2-, PM_x- and NO_x-emissions.

Vehicle movements conventional structure

The vehicle movements for the conventional construction logistics structure were subdivided into six vehicle categories: van, heavy truck, kipper, light truck, concrete truck for piles, concrete truck and waste truck. The calculated numbers for these categories indicate the number of round trips necessary for the logistics structure. The vehicle movements per vehicle category were calculated for three construction phases: preparation construction site, substructure & shell construction and final construction. This means that two construction phases, the substructure construction and the shell construction, were merged to simplify the calculations. These calculations were performed for two construction methods, the hybrid and circular construction method, explained in subsection 3.3.2. The vehicle movements for the hybrid method were calculated for both Centrumeiland and Strandeiland. As the construction method shifts to circular construction in 2030, the vehicle movements for circular construction were only determined for Strandeiland. This due to the fact that the construction activities on Centrumeiland will be finished before 2030. Based on these calculations, the vehicle movements per time period were determined for IJburg II. This was necessary because some construction periods of Centrumeiland and Strandeiland will overlap. Ultimately, the total vehicle movements for 2020-2029 and 2030-2038 were determined. The exact calculations performed in this step are displayed in appendix G.1.

Vehicle movements new designs construction logistics structure

This step in the calculation model calculated the vehicle movements for the new logistics structure designs based on the vehicle movements of the conventional logistics structure. The addition of a construction logistics centre to the construction logistics structure has a certain effect on the vehicle movements. Per construction logistics centre was identified how this would influence the construction logistics structure and which calculations had to be done to express this effect in vehicle movements. The calculations done to convert the conventional logistics structure to the three new logistics structure designs are illustrated in appendix G.2. The change in the construction logistics structures led to vehicle movements of three new vehicle categories: push barge, transshipment and last-mile transport. The categories push barge and last-mile transport are expressed in number of round trips necessary for the logistics structure. The category transshipment is displayed in the number of necessary transshipment movements for the construction logistics structure.

CO_2-, PM_x- and NO_x-emissions construction logistics structure

In this calculation phase, the CO_2-, PM_x- and NO_x-emissions were calculated for the four construction logistics structures. For this purpose, assumptions were made regarding emission factors and distances between multiple centres and IJburg II. The emission factors are displayed in table 10 and the distances in appendix H. The total emissions were determined with well-to-wheel-emission factors which means that not only emissions resulting from the combustion of fuels were considered but also emissions released during the extraction, transportation and refining of fuels or the production and transportation of electricity. Two types of emission factors were used: EURO VI emissions factors for transport vehicles on fossil fuels and electric emission factors for emission-free transport. For each vehicle category the emissions were calculated per construction phase which made it possible to determine the total emissions. Based on these numbers, the reductions of emissions were calculated for the new construction logistics structures with respect to the conventional structure. Important to note is that it was assumed that the last-mile deliveries are conducted with light electric trucks. This was done in order to be able to calculate the structures properly. The detailed calculations of this step can be found in appendix G.3.

Table 10: EURO VI & electric emission factors

Vehicle type	CO_2 [g/tkm]		PM_x [g/tkm]		NO_x [g/tkm]	
	Euro VI emission factors	*Electric emission factors*	*Euro VI emission factors*	*Electric emission factors*	*Euro VI emission factors*	*Electric emission factors*
Van	1153,0	853,2	0,115	0,110	4,540	0,798
Heavy truck	78,0	61,62	0,008	0,006	0,078	0,032
Kipper	104,0	82,16	0,012	0,010	0,156	0,065
Light truck	204,0	161,16	0,029	0,027	0,164	0,141
Concrete truck for piles	104,0	82,16	0,012	0,010	0,156	0,065
Concrete truck	104,0	82,16	0,012	0,010	0,156	0,065
Waste truck	204,0	161,16	0,029	0,027	0,164	0,141
500 ton push barge	44,0	34,76	0,022	0,008	0,570	0,062
Transshipment [g/ton]	782,6	637,0	0,195	0,008	7,8	0,169
Last-mile transport	204,0	161,16	0,029	0,027	0,164	0,141

6.4 Results

This subsection represents the results of the calculation model. First, the vehicle movements for the conventional structure and the new designs are discussed. Thereafter, the results relating to the reduction of CO_2-, PM_x- and NO_x-emissions for the new designs in respect to the conventional structure are explained.

Vehicle movements

The vehicle movements are displayed as average per week for the conventional construction logistics structure and the new construction logistics structure designs. An overview of the average vehicle movements per week for the new designs and the conventional structure is given in table 11. The vehicles movements are displayed for three time periods: 2020-2029 (hybrid construction period), 2030-2038 (circular construction period) and 2020-2038 (total construction period). In addition, a distinction was made in vehicle movements to IJburg II, vehicle movements on IJburg II and barges to IJburg II. The results per category are discussed below. In addition, one vehicle or barge movement represents one round trip. The more detailed vehicle movements per vehicle type and construction phase can be found in appendix I.1.

Table 11: Overview of average vehicle & barge movements per week

	Conventional structure	Design 1	Design 2	Design 3
Average vehicle movements to IJburg II 2020-2029 [vehicles/week]	204	123	77	151
Average vehicle movements to IJburg II 2030-2038 [vehicles/week]	191	87	99	137
Average vehicle movements to IJburg II 2020-2038 [vehicles/week]	197	105	88	144
Average vehicle movements on IJburg II 2020-2029 [vehicles/week]	204	217	184	193
Average vehicle movements on IJburg II 2030-2038 [vehicles/week]	191	225	225	200
Average vehicle movements on IJburg II 2020-2038 [vehicles/week]	197	221	204	197
Average barge movements to IJburg II 2020-2029 [barges/week]	0	5	8	0
Average barge movements to IJburg II 2030-2038 [barges/week]	0	6	7	0
Average barge movements to IJburg II 2020-2038 [barges/week]	0	6	8	0

Vehicle movements to IJburg II

The vehicle movements to IJburg II are defined as all the vehicles that are required for the supply logistics of construction materials. The results in table 11 clearly show that the average vehicle movements to IJburg II over the time period 2020-2038 in all new logistics structures decrease compared to the conventional structure (197 vehicle movements per week). Design 2 scores best (88 movements) followed by design 1 (105 movements) and design 3 (144 movements). The decline in vehicle movements is caused by the shift to waterborne transport, by producing ready-mixed concrete at the site and by bundling cargo loads at or near suppliers/wholesalers.

When zooming in on the two time periods, design 1 has by far the most vehicle reductions in the period 2020-2029 compared to the conventional structure. In this design 77 vehicles movements will come to IJburg II instead of the 204 movements which is a 60% reduction. In addition, design 2 (123 movements) and design 3 (151 movements) also show a high vehicle reduction of respectively 40% and 25% in comparison with the conventional structure. For the time period 2030-2038, design 1 displays the largest decline of vehicle movements compared to the conventional structure: 87 vehicle movements against 191 per week. Design 1 scores better than design 2 (99 movements) in this time period because less ready-mixed concrete is used due to the shift to circular construction materials. As a result, production at the site of ready-mixed concrete is less effective for vehicle reductions. Furthermore, design 3 (137) also outperforms the conventional structure but shows the lowest vehicle movement reduction of the three new designs.

Vehicle movements on IJburg II

The vehicle movements on IJburg II are defined as all the vehicles that are required for the site logistics of construction materials (also last-mile delivery). Table 11 indicates that on average over the period 2020-2038 design 3 requires the same number of vehicle movements as the conventional structure (197 movements). What is striking is that over the same period, design 1 (221 movements) and design 2 (204 movements) show a small rise in vehicle movements per week relative to the conventional structure. The explanation for this rise can be found in the fact that from the logistics centres smaller electric vehicles are deployed for last-mile distribution. While, the conventional structure makes use of larger (more polluting) vehicles. The implementation of a logistics centre thus increases the frequency of the vehicles on IJburg II.

When looking more closely into the two time periods, a number of things stand out. First, both design 2 (184 movements) and design 3 (193 movements) for the time period 2020-2029 reduce the number of vehicle movements per week relative to the conventional structure (204 movements) with respectively 10% and 5%. Second, design 1 (217 movements) shows a small increase of vehicle movements of 5%. Third, all the new designs for the period 2030-2038 increase the vehicle movements on IJburg II compared to the conventional structure. This can again be explained by the deployment of small electric vehicles for last-mile deliveries. Design 1 and 2 both require 225 vehicle movements on IJburg II instead of 191 movements in the conventional structure. Design 3 scores best of the three new designs from this point of view with 200 vehicle movements.

Barge movements

Barge movements represent all the barges that are required for the delivery of construction materials and disposal of waste for IJburg II. As can be seen in table 11, there are no barge movements for the conventional structure and design 3, as no waterborne transport is incorporated in these construction logistics structures. In design 1 and 2, waterborne transport is included which brings barges to IJburg II. For the time period 2020-2038, design 1 requires 6 barge movements per week and design 2 requires 8. Most of the barge movements in design 1 are generated for the transport of heavy construction materials. Furthermore, most barges in design 2 are used for the transport of minerals required for producing ready-mixed concrete at IJburg II.

When looking at the two time periods in more detail, design 1 demands 5 barge movements per week in the period 2020-2029 against 6 in 2030-2038. Moreover, design 2 requires 8 barge movements per week in 2020-2029 and 7 in 2030-2038.

Reduction CO_2-, PM_x- and NO_x-emissions

The reduction of CO_2-, PM_x- and NO_x-emissions of the new construction logistics structure designs in respect to the conventional structure are shown in table 12. Per emission category, it is indicated which design scores best (green), moderate (orange) or worst (red). The total CO_2-, PM_x- and NO_x-emissions caused by vehicle movements for the conventional structure and the three newly designed structures are displayed in appendix I.2. For each design, the results of the emission reductions are discussed into detail below. In addition, the Municipality of Amsterdam was curious about the results in the case that no changes are made to the construction logistics structure. Therefore, these results are elaborated last.

Table 12: Percentage reduction CO_2-, PM_x- and NO_x-emissions new designs with respect to conventional construction logistics structure

	Design 1	Design 2	Design 3
Reduction CO_2-emissions [%]	32,07	16,10	34,89
Reduction PM_x-emissions [%]	20,61	52,99	40,11
Reduction NO_x-emissions [%]	27,80	25,55	50,92

Design 1

This new design scores on all three emissions a reduction compared to the conventional structure. However, for no type of emission, it scores the highest reduction out of the three designs. In addition, in terms of PM_x-emissions it shows the lowest reduction (20,61%) of all designs which still is a quite high reduction. The CO_2-, PM_x- and NO_x-emissions are particularly decreased due to waterborne transport for heavy construction materials and to a lesser extent by the implementation of a CCC. However, waterborne transport is not for every construction material an outcome because transport of sand by water leads to an increase in CO_2- and PM_x-emissions.

Design 2

Design 2 is in terms of reducing CO_2- and NO_x-emission the worst option out of the three new designs and in case of reducing PM_x-emissions the best option. The largest part of the reduction in PM_x-emissions can be attributed to producing ready-mixed concrete at IJburg II which leads to far fewer vehicle kilometres of polluting concrete trucks. However, the production at the site will lead to more transshipment on IJburg II which increases the NO_x-emissions compared to the conventional structure. NO_x-emissions are mostly decreased by the use of a CCC and a decoupling point for road transport from 2030. The CO_2-reduction is mainly caused by the implementation of a CCC and by producing ready-mixed concrete at IJburg II.

Design 3

For the reduction of CO_2- and NO_x-emissions, design 3 is the best option out of the new designs. The CO_2-reduction is entirely due to the implementation of centres for bundling at the source. What is striking that due to the rise of transshipment activities, a collection point of waste for sand lead to higher CO_2-, PM_x- and NO_x-emissions. The same applies for a collection point of waste for reverse flows and a decoupling point for road transport regarding CO_2-emissions. In addition, the reduction of PM_x- and NO_x-emissions is also for the biggest part for the account of bundling at the source.

Scenario: no changes in construction logistics structure

The Municipality of Amsterdam was interested in the reduction of emissions if the Municipality is not actively trying to change the construction logistics structure. Therefore, the emission reductions for this scenario were calculated. In this scenario, it was assumed that nothing changes to the conventional logistics structure until 2030. From 2030, it was presumed that electric vehicles are able to transport heavy construction materials over short distances and light materials over longer distances, as is described in subsection 5.2.2. For the calculation model, this means that electric emission factors were considered for vans, kippers, concrete trucks and waste trucks after 2030. This scenario led to the following results: a CO_2-reduction of 4,4%, a PM_x-reduction of 1,7% and a NO_x-reduction of 22.2%. From these outcomes can be concluded that the ambition of the Municipality of Amsterdam with respect to the CO_2-reduction is not achieved in this scenario. In addition, it can be stated that the deployment of electric vehicles primarily has a positive effect on the reduction of NO_x-emissions.

6.5 Model verification and sensitivity analysis

In this subsection, it is examined if the calculation model is logical and consistent. This process is called model verification. In addition, a sensitivity analysis is performed to determine how uncertainties in the input influence the outcomes of the calculation model.

The model verification was done by checking the dimensions of the equations in the calculation model. For each calculation it was checked whether the unit of the result complied with the units used in the calculation. The sensitivity analysis was conducted by identifying three uncertain inputs in the calculation model. These inputs were modified with a realistic multiplication factor for this uncertainty to check whether this rise or decrease led to other conclusions. Therefore, the new outcomes were tested on the requirements (need to haves 6, 7 and 8) to determine if these requirements were still met. The three changed input values in the calculation model are:

1. Vehicle movements based on the reference project: van, heavy truck and light truck.
2. Load factor per construction phase.
3. The number of piles required for 1 house.

The results of the sensitivity analysis on the CO_2-, PM_x- and NO_x-reduction (need to haves 6, 7 and 8) are explained per input value below.

Vehicle movements van, heavy and light truck

For the vehicle movements, the multiplication factors 1,25 and 0,75 were chosen because a higher increase or decrease than 25% for these vehicle movements is not expected. From table 13 can be concluded that a 25% increase and 25% decrease of the above named vehicle movements do not influence the suitability of the designs based on the CO_2-, PM_x- and NO_x-emissions. Design 1 and 3 comply to the requirements, design 2 does not. In addition, from the table below can be concluded that design 2 and 3 are more sensitive to the differences in the vehicle movements than design 1. Less vehicle movements of vans, heavy and light trucks contributes to a higher reduction of emissions for design 2, while for design 3 exactly the opposite is true.

Table 13: 25% increase or decrease of the vehicle movements van, heavy truck and light truck

	Multiplication factor	Reduction CO_2 [%]	Reduction PM_x [%]	Reduction NO_x [%]
Design 1	*1,25*	32,72	20,14	28,65
	0,75	31,19	18,72	35,36
Design 2	*1,25*	14,20	54,19	26,73
	0,75	21,27	51,36	40,43
Design 3	*1,25*	34,54	39,88	51,10
	0,75	26,64	23,91	50,67

Load factor per construction phase

For the load factor a rise and decline of 20% was chosen. From table 14 can be stated that the decrease and increase of the load factor per construction phase do not influence the suitability of the designs based on the CO_2-, PM_x- and NO_x-emissions. Design 1 and 3 meet the requirements, design 2 does not. Furthermore, it can be stated that design 3 is most sensitive to changes in the load factor; a lower load factor lead to higher reductions of emissions.

Table 14: 20% increase or decrease of load factor per construction phase

	Multiplication factor	Reduction CO_2 [%]	Reduction PM_x [%]	Reduction NO_x [%]
Design 1	*1,20*	31,83	20,23	27,61
	0,80	32,32	21,00	28,00
Design 2	*1,20*	15,87	52,82	25,47
	0,80	16,33	53,16	25,62
Design 3	*1,20*	31,22	36,19	47,91
	0,80	38,56	44,03	53,93

Number of piles per house

The sensitivity analysis for the number of piles per house was performed with the factors 1,50 and 0,50. This because it is imaginable that many more piles per house are required due to a lower load-bearing capacity of the soil or less piles are necessary due to a new foundation method. Table 15 shows that a 50% increase or decrease of the number of piles per house do not influence the suitability of the designs based on the CO_2-, PM_x- and NO_x-emissions. Design 1 and 3 comply to the requirements, design 2 does not. Moreover, in this table can be seen that increasing or decreasing the number of piles with 50% does not significantly influence the reduction of emissions.

Table 15: 50% increase or decrease of number of piles per house

	Multiplication factor	Reduction CO_2 [%]	Reduction PM_x [%]	Reduction NO_x [%]
Design 1	*1,50*	31,45	20,27	27,80
	0,50	32,74	20,98	27,82
Design 2	*1,50*	16,99	52,44	24,81
	0,50	15,16	53,58	26,32
Design 3	*1,50*	34,18	39,18	50,30
	0,50	35,64	41,10	51,57

Sub-conclusion

From model verification and sensitivity analysis can be concluded that the developed model is logical and consistent. Furthermore, it was proven that by changing a number of uncertain input values in the calculation model with a realistic multiplication factor, the conclusions about the suitability of the designs for IJburg II do not change. Furthermore, it can be stated that out of the three new designs, design 3 is the most sensitive for the implemented improvements. In particular, changes in the vehicle movements and the load factor influence the reduction of emissions for design 3.

6.6 Design verification

A design verification should be performed to examine if the design synthesis resulted in designs that comply to the system requirements (Leonard, 1999). Therefore, this subsection elaborates upon the design verification for the new construction logistics structures developed in subsection 5.3. The new structures were tested on the drafted requirements in subsections 4.2 and 4.3. The need to haves and nice to haves were tested quantitatively by means of the developed calculation model and qualitatively by using the design descriptions of subsections 5.1 and 5.2.3. The requirements that were tested with the calculation model are indicated with an asterisk in the tables. The results of the design verification for the three new designs are illustrated in tables 16 and 17. For the need to haves a check mark was used to indicate that the design fulfills the requirement. A check mark in the box represents that the design fulfills the requirement. An empty box means that the requirement was not achieved by the design.

Table 16: Verification need to haves three new designs

	Need to haves (constraints)	Design 1	Design 2	Design 3
1.	The construction logistics structure should be able to transport construction materials for residential and non-residential structures from the supplier or wholesaler to IJburg II.	✓	✓	✓
1a.	The construction logistics structure should be able to transport heavy and large construction elements.	✓	✓	✓
2.	The construction logistics structure must guarantee on-time construction material deliveries.	✓	✓	✓
2a.	The construction logistics structure must be able to deliver non time-critical construction materials one day after call-off.	✓	✓	✓
2b.	The construction logistics structure must be able to deliver time-critical rush orders within a day.	✓	✓	✓
2c.	The construction logistics structure must be able to transport ready-mixed concrete to the construction site within three hours.	✓	✓	✓
3.	The construction logistics structure must be able to distribute construction materials for residential and non-residential structures on IJburg II.	✓	✓	✓
4.	The construction logistics structure must be able to collect, transport and store waste flows on IJburg II.	✓	✓	✓
5.	The construction logistics structure must be able to serve the residential and non-residential construction activities of IJburg II from 2020 until 2038.	✓	✓	✓
6.*	The construction logistics structure must reduce CO_2-emissions due to construction logistics movements with at least 25% compared to the conventional logistics structure.	✓		✓
7.*	The construction logistics structure must reduce NO_x-emissions compared to the conventional construction logistics structure with at least 1%.	✓	✓	✓
8.*	The construction logistics structure must reduce PMx-emissions compared to the conventional construction logistics structure with at least 1%.	✓	✓	✓
9.	The construction logistics structure must not severely damage the construction materials.	✓	✓	✓

As can be seen in table 17, the nice to haves were rated on a scale from 1 to 5. A scale-based assessment was chosen because a design does not simply meet the nice to have as is the case with the need to haves. With nice to haves, one design can score better on a requirement than another. The numbers in table 17 represent how a design scores on a requirement; 1: very negative, 2: negative, 3: neutral, 4: positive and 5: very positive. Nice to haves 4 and 5 were rated quantitatively, namely based on the outcomes of the calculation model. The other four were rated qualitatively based on insights gathered in conversations with the Municipality of Amsterdam. When summing up the total scores of the designs, it was assumed that each requirement is equally important.

Underpinning scores nice to haves

1. Designs 1 and 2 include waterborne transport which is very positive for the requirement. Design 3 does not incorporate transport by water and thus scores negative on this requirement.
2. All the three designs negatively influence the noise and visual hindrance on IJburg II, as construction logistics centres are used on the two islands. In addition, design 2 scores a very negative because of the use of a concrete plant on IJburg II.
3. The three logistics structures can support the logistics activities after 2038 which is positive. Designs 1 and 2 are rated as very positive because of the possibility of continuing to supply IJburg II over water after 2038.
4. All three the designs are assessed as positive because they reduce the vehicle movements to IJburg II. Design 3 reduces these vehicle movements slightly less than the other two.
5. Designs 1 and 2 score negative on this requirements because of the increase in vehicle movements on the islands compared to the conventional structure. Design 3 rates neutral, as vehicle movements not increase or decrease relative to the conventional structure.
6. The three designs hinder the construction activities, as construction logistics centres on IJburg are used. These centers will have to be located where other facilities are currently planned. Design 2 is assessed as very negative since a concrete plant takes up a lot of space.

Table 17: Verification nice to haves three new designs

	Nice to haves (objectives)	Design 1	Design 2	Design 3
1.	The construction logistics structure should be able to transport construction materials for residential and non-residential structures by water.	5	5	2
2.	The construction logistics structure should be low in visual and noise hindrance for current and future inhabitants.	2	1	2
3.	The construction logistics structure should be able to serve the logistics structure for IJburg II to supply freight and dispose waste after 2038.	5	5	4
4.*	The construction logistics structure should decrease the road congestion compared to the conventional construction logistics structure.	5	5	4
5.*	The construction logistics structure should increase the traffic safety on IJburg II compared to the conventional construction logistics structure.	2	2	3
6.	The construction logistics structure should minimize the hinder to construction activities.	2	1	2
Total		21	19	17

Outcomes

From the design verification can be concluded that two of the three designed construction logistics structures, design 1 & 3, comply to all the need to haves. As can be seen in table 16, design 2 does not fulfill the need to have of a 25% reduction of CO_2-emissions relative to the conventional construction logistics structure. As a result, this design cannot be seen as a feasible solution. The total scores of the nice to haves clearly indicate that design 1 is the most favourable design (21 points), followed by design 2 (19 points) and design 3 (17 points). Since design 2 is an infeasible solution, it does not need to be considered in this comparison. Design 1 is more favourable than design 3 because of the incorporation of waterborne transport and the expected higher decrease of congestion due to construction logistics. However, design 3 scores better on traffic safety than design 1, as design 3 does not increase the vehicle movements on IJburg II compared to the conventional structure.

6.7 Sub-conclusion

A calculation model in Microsoft Excel was developed to calculate the vehicle movements and the CO_2-, PM_x- and NO_x-emissions for construction logistics per design. Logistics data of a reference construction project and a number of assumptions were used to develop this model. The new designs were tested on the requirements both qualitatively and quantitatively. The qualitative test was carried out by checking whether the requirement was present in the design of the new construction logistics structure or not. The quantitative test was performed with the calculation model. The outcomes of the calculation model showed significant reductions in emissions for all three new designs. In addition, the results of the designs displayed a high decrease of required transport towards IJburg II, but an equal amount or even small increase of vehicles on IJburg II. The three designs were tested on the requirements in the design verification. The need to haves were tested binary, while scores were used for the nice to haves. From the design verification can be concluded that two of the three designs, design 1 and 3, fulfill the need to haves (minimal requirements). Out of the two designs that comply to the need to haves, design 1 scores best on the nice to haves due to the inclusion of waterborne transport and a higher decrease of congestion by construction logistics movements.

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7 Evaluation Construction Logistics Structures IJburg II

Nowadays, new logistics concepts have to serve multiple values related to multiple interest of a growing number of stakeholders (van Duin, 2012). According to Ballantyne et al. (2013), the needs and perspectives of stakeholders should be considered to improve urban freight transport. In addition, Stathopoulos et al. (2012) stated that the introduction and implementation of new logistics structures are at risk if stakeholder perceptions are not taken into account. Furthermore, Sullivan et al. (2011) qualified changing the construction logistics structure as a highly complex problem because of the large amount of stakeholders. All of the above implies that stakeholders play a key role in the construction logistics structure. The Municipality of Amsterdam should involve the main stakeholders in order to change the construction logistics structure. Therefore, the goal of this section is *to evaluate the feasible construction logistics structures on the stakeholders' perceptions*.

The evaluation of the new construction logistics structures was only performed from a stakeholder point of view which means that the feasible designs are not evaluated based on other important criteria such as costs, safety, required land for logistics centres and performance. The new designs should also be evaluated on these points but this thesis does not address these criteria due to time limitations.

In this section, the main stakeholders of the construction logistics structure and their interest are identified first by means of a stakeholder analysis. Second, the influence and interaction pathways for each stakeholder group are explored by means of a power-interest grid and a stakeholder-influence diagram. Subsequently, the roles of the three most influential stakeholders (the Municipality of Amsterdam, the contractors and the project developers) for implementation are discussed. Thereafter, the two new suitable construction logistics structures (design 1 and 3) are evaluated based on the stakeholders' perceptions. The perceptions of the following six stakeholder groups are evaluated: the Municipality of Amsterdam, contractors, project developers, freight transporters (waterborne and road) and new inhabitants of IJburg II. At the end of this section, a start is made for an implementation plan for construction logistics structure design 1.

7.1 Stakeholders

First, it is important to define the term stakeholder:

a stakeholder is that actor who influences the issue as well as the one who is being influenced by the problem (Macharis, 2005).

A division can be made in direct and indirect actors (Balm et al., 2018). Direct stakeholders are economic actors who are directly involved in the construction and decision-making process. Indirect stakeholders are the societal actors who experience hindrance of the construction activities and are not involved in the building process (Balm et al., 2018).

The first step in the stakeholder analysis was to identify relevant stakeholders in the construction logistics structure for IJburg II. The identified relevant stakeholders are listed below with a short description.

The Municipality of Amsterdam

The Municipality is one of the most important stakeholders. The Municipality fulfills a number of roles in the development of IJburg II and in the construction logistics structure. These roles are elaborated below:

- *Landowner*: The Municipality initially owns all the land on Centrumeiland and Strandeiland. This land is sold or leased to project developers (from a large developer to a private builder). The department of Grond & Ontwikkeling (G&O) is responsible for issuing the land.
- *Legislative and directive*: Drawing up policy strategies and ambitions related to the construction process and the construction logistics structure.
- *Guardian public interest*: One of the key roles of the Municipality of Amsterdam is to guard the collective interests of all inhabitants. This means that the Municipality should provide a livable, accessible and safe city.

Contractor

The main executor of the construction process. In this function, the contractor is responsible for the entire construction process and the timely and tidy delivery of the buildings to the project developer. For IJburg II, especially for Strandeiland, it is expected that a number of large contractors will build the largest amount of residential and non-residential buildings.

Subcontractor

The subcontractor is a party that works for the contractor. Often, contractors outsource different specialized construction activities to subcontractors. The expectation is that a wide variety of subcontractors will construct on IJburg II. Certainly on Centrumeiland, where private builders can choose their own subcontractors.

Private builders

Some building plots at IJburg II will be issued to private individuals. The private builders are the people that develop their own house. The private builders will probably hire subcontractors to construct parts of the houses.

Project developer

The project developer is a large company interested in developing urbanized regions. The project developer subscribes to the tenders issued by the Municipality of Amsterdam for area developments at IJburg II. Once a tender has been won, the project developer hires a contractor to partly or fully do the construction works for that particular developing project. The project developer is therefore the owner of the houses and buildings. It is expected that a number of large developers will compete for large developing projects at IJburg II. Probably many developing contractors: a project developer and contractor in one.

Supplier

The producing and supplying party of construction materials. Full-truckloads of materials can be ordered directly by the supplier but no small batches. Important suppliers for residential and non-residential development will be suppliers of ready-mixed concrete, prefab elements and wood.

Wholesaler

A supplying party of construction materials. The wholesaler can deliver all different kinds of construction materials. However, generally spoken, the wholesaler supplies the somewhat smaller construction materials. This will also be the case for IJburg II.

Road freight transporter

The stakeholder that provides the transport of construction materials over land from the supplier/wholesaler to the client. Road transport to IJburg II can be carried out with multiple types of trucks or vans.

Waterborne freight transporter

The stakeholder that provides the transport of construction materials by water from the supplier/wholesaler to the client. Waterborne transport to IJburg II will be conducted with barges.

Logistics service provider

The company that arranges transports for construction materials between the supplier/wholesaler and the construction site. The logistics service provider can perform this operations itself or engage other parties for this purpose such as freight transporters. The logistics service provider can also operate a potential construction logistics centre on IJburg II.

Waste processor

The actor that provides the collection of waste at IJburg II and the disposal of reverse flows during construction activities and thereafter. A number of particular waste processors are active in the Amsterdam area such as AEB Amsterdam, Renewi and SUEZ.

Inhabitants IJburg

The group of people who currently live near IJburg II. These inhabitants will be affected by the construction activities and the construction logistics structure. In addition, this group also includes the future new inhabitants of Centrumeiland and Strandeiland.

Environmental organizations

The groups fighting for the preservation of flora and fauna on and around IJburg.

Interests and influence stakeholders

The above listed stakeholders were analyzed into more depth. The interest in and the influence on the construction logistics structure of these stakeholders was determined. The results are displayed in table 18. The first column gives an overview of the stakeholders. The second column states the interests of the stakeholders in the logistics structure. The last column indicates the influence a stakeholder can exert on the logistics structure. The influence is defined as the ability of a stakeholder to make demands on the construction logistics structure which can be seen as a form of participation. The degree of influence is expressed in high (green), medium (orange) or low (red). High means a lot of participation while low means little voice. The interests and influence of the different stakeholders were identified by doing desk and literature research; and during preliminary discussion groups with multiple stakeholders.

Particularly, the articles of Macharis et al. (2016) and Balm et al. (2018) were useful to gain insight in the stakeholders' interests.

Table 18: List of stakeholders for IJburg II

Stakeholder	Interest	Influence
Municipality of Amsterdam	The achievement of the ambitions in terms of accessibility, environment, circularity and sustainable (construction) logistics; a good quality of life for citizens, positive business climate, ease of implementation	High
Contractor	The construction must be as efficient as possible with reliable material deliveries, low costs and a safe construction environment for people and materials.	High
Subcontractor	The construction must be as efficient as possible with reliable material deliveries, low costs and a safe construction environment for people and materials.	Medium
Private builders	Reliable material deliveries, safe construction environment and accessible construction site.	Medium
Project developer	Affordability and good quality of construction works, marketable buildings, rapid completion, allocation of construction ground by the municipality.	High
Supplier	Detailed and on-time orders, low transport costs, punctual and safe pickups, reliable deliveries.	Medium
Wholesaler	Detailed and on-time orders, low transport costs, punctual and safe pickups, reliable deliveries.	Medium
Road freight transporters	Quick pickups/deliveries, flexible pickup/delivery times, profitable operations, receiver and supplier/wholesaler satisfaction, full-truckloads, attractiveness road transport.	Low
Waterborne freight transporters	Quick pickups/deliveries, flexible pickup/delivery times, profitable operations, receiver and supplier/wholesaler satisfaction, full-truckloads, attractiveness transport by water	Low
Logistics service provider	Profitable operations, receiver and supplier/wholesaler satisfaction, punctual and quick pickups/deliveries	Low
Waste processor	Full-truckloads, ease and quick pick-up of waste.	Low
Inhabitants	Positive impact on traffic safety; reduction of emissions, freight movements, noise and visual nuisance; less congestion.	Medium

7.2 Power & influence stakeholders

Power-interest grid

The power-interest grid is an useful tool to determine the position of stakeholders in terms of interest and power. The outcomes should be taken into account in order to successfully address the issue (Bryson, 2004). The power-interest grid can basically be separated in four quadrants. The upper right quadrant represents the players who have both a high interest and high power. The upper left quadrant indicates the subjects with high interest but low power. The lower right box show the context setters who have substantial power but less interest. Last, the lower left box represents the crowd who have little interest and power (Bryson, 2004). Evidently, the stakeholders with high power and high interest (players) need to be taken into account. However, also the so called context setters should not be forgotten, because these can have a substantial influence on the problem when a project or solution influences their interests.

A power interest-grid was made to identify the main stakeholders for the construction logistics structure for IJburg II. The power-interest grid is displayed in figure 20. From the power-interest grid can be clearly stated that many stakeholders have a high interest and power in the logistics structure. This makes adjusting the logistics structure complex and delicate. The stakeholders in the power-interest grid are the stakeholders identified in subsection 7.1. Five groups of stakeholders can be considered as subjects which means that they will not be of influence in the decision-making process of a new logistics structure. However, the environmental organisations, logistics service providers, waste processors, waterborne transporters and road transporters need to be informed about the process. Otherwise, they can try to slow down the process. All the other stakeholders should be taken into account in the decision-making process because they are powerful and have a high degree of interest. The stakeholders in the upper right quadrant are from now on the key stakeholders of the construction logistics structure for IJburg II.

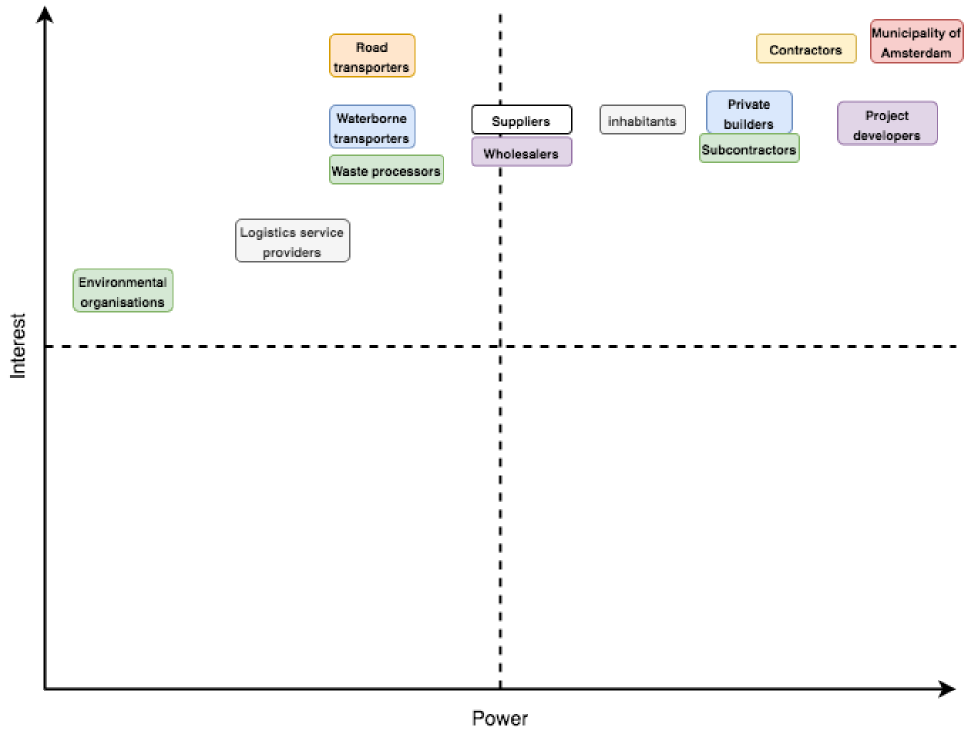

Figure 20: Power-interest grid

Reflection power-interest grid

The Municipality of Amsterdam is identified as the stakeholder with the highest power and interest. This is based on two arguments. One, the Municipality operates as landowner and as a regulative and directive power on IJburg II which means high power. Two, the Municipality is responsible for a livable city which gives the Municipality a high interest in the construction logistics structure. This is due to the fact that construction logistics puts a high burden on the urban environment. In addition, it should be stated that this power-interest grid, with these outcomes, is valid for the preliminary phase of the construction project IJburg II. The Municipality of Amsterdam is certainly very influential in the run-up to the construction project, as during this period regulations and legislation are drawn up and requirements can be set for construction logistics in tenders. However, as the construction project progresses, the power of the Municipality of Amsterdam will diminish because legislation is already in force. Furthermore, the opportunity to influence construction logistics in tenders has also expired.

Stakeholder-influence diagram

The stakeholder-influence diagram illustrates how the relevant stakeholders in the power-interest grid influence each other (Eden and Ackermann, 2013). The interaction pathways between stakeholders is interesting to know for the Municipality of Amsterdam. In this way, the Municipality is able to strategically influence the stakeholders of the construction logistics structure as effective as possible. This should lead to changes in the construction logistics structure in favour of the ambitions of the Municipality of Amsterdam.

The stakeholder-influence diagram is depicted in figure 21. The diagram is again made for the preliminary phase of the construction project. *The circle size* indicates the overall influence, *the line direction* shows the effect of the influence and *the line width* illustrates the strength of the influence. As can be seen in figure 21, the two most influential stakeholders are the Municipality of Amsterdam and the project developers. This is because both stakeholders can set requirements for construction logistics. The Municipality and project developers hire the contractors which means that the contractor should comply with these requirements. Subsequently, the subcontractors that are hired by the main contractors should also follow these requirements. The contractors choose at which suppliers and wholesalers the construction materials are bought. For this reason, the contractors influence the suppliers and wholesalers. In their turn, the suppliers and wholesalers can influence the freight carriers and logistics service providers by setting requirements for the transport. The waste processor is mainly influenced by the Municipality of Amsterdam due to regulations.

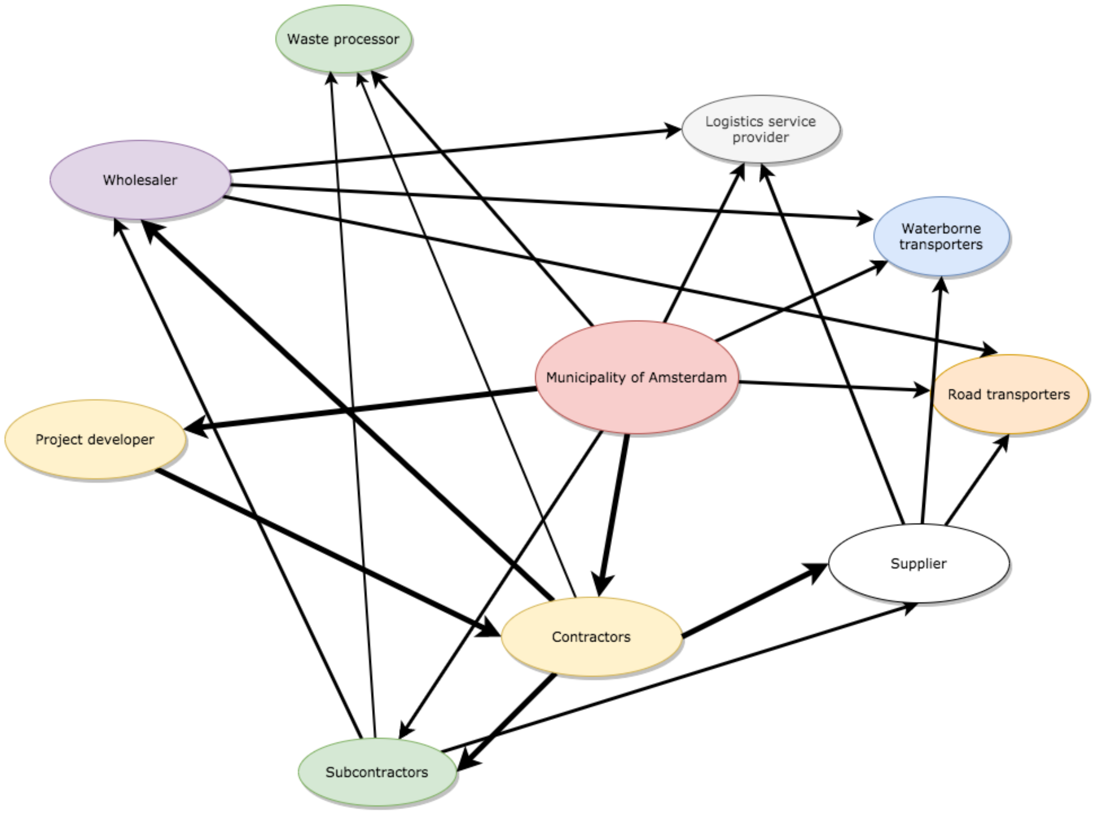

Figure 21: Stakeholder-influence diagram

7.3 Project developers & contractors

From the stakeholder-influence diagram was concluded that the project developers and contractors play a crucial role in the implementation of a new construction logistics structure. Therefore, the project developers and contractors on IJburg II were explored into more detail.

The residential and non-residential development on IJburg II will mainly be conducted by three types of developers: private developers/builders, project developers and the Municipality of Amsterdam. On both islands, the contractors will be appointed by the developers. At this moment, it is still not clear which party is exactly going to develop on IJburg II. However, it is clear for what kind of developer the land is available. Therefore, based on this information, an indication was made about the expected project developers and contractors per island. In addition, it was explored how this composition of developers and contractors can influence the construction logistics structure.

Centrumeiland

When looking at Centrumeiland, 10% of the new build houses is granted to project developers through tenders, 20% is social housing and the other 70% is destined for private developers/builders and construction groups (15% private builders and 55% construction groups) (Gemeente Amsterdam, 2016). That 70% of the building plots are available for private builders and construction groups makes the construction activities on Centrumeiland unique. However, each private builder chooses its own contractor. This leads to a situation with many different contractors constructing on Centrumeiland. Moreover, each contractor has long-term agreements with its own suppliers and wholesalers of construction materials.

This causes difficulties in streamlining the construction logistics process because cooperation between all these different contractors and suppliers is required for efficient logistics operations. The other 30% of the building plots are most certainly developed by large contractors or developing contractors.

Strandeiland

On Strandeiland, 40% of the 8000 houses are intended for social housing, a maximum of 10% is reserved for private builders and the remaining 50% is granted to project developers through tenders (Gemeente Amsterdam, 2019b). In view of the low percentage of private building plots and the high percentage of social housing and plots intended for large project developers, it is likely that mainly large contractors and developing contractors build on Strandeiland. Given the size of the construction project, it is expected that not one but several large contractors will be building on Strandeiland.

Implications for Municipality of Amsterdam

Generally spoken, it is more easy for the Municipality of Amsterdam to influence and engage a few large contractors than various smaller contractors. In the first place because large contractors set an example for the construction industry and are rather inclined to change their way of working. In addition, these companies have the financial ability to be one of the first pioneers in the transition to a more sustainable construction logistics structure. In the second place because custom-made agreements between the Municipality of Amsterdam and the large contractors can be made on a more sustainable structure and possible compensation measures to meet the contractors' needs. With several smaller contractors, the Municipality of Amsterdam has less control over this process.

The reasoning from above is also supported by the conclusions of a consultation session on construction logistics with a number of large contractors. The majority of the contractors stated that they are willing to change their construction logistics structure. However, most of the contractors indicated that the change will only be initiated if imposed in legislation by the Municipality of Amsterdam because they do not feel the intrinsic urge to change the logistics structure on their own. This implies that legislation or other incentives are necessary to let contractors move in the direction of a new structure.

7.4 Municipality of Amsterdam

The Municipality of Amsterdam aims to change the construction logistics structure in such a way that the ambitions are met. However, the Municipality of Amsterdam cannot change the structure on its own and is dependent on the cooperation of stakeholders. The stakeholders in the construction logistics structure can be influenced by the Municipality of Amsterdam by means of control options. What control options will be necessary depends on the willingness of stakeholders to cooperate in a new structure. The control options of the Municipality of Amsterdam are evaluated in this subsection.

The control options are classified in four categories (Quak et al., 2011):

1. **Regulation**: drawing up unambiguous policy strategies and regulations for construction logistics.
2. **Coordination**: setting up an organisation and consultation structure in which all stakeholders must participate to discuss the bottlenecks and challenges in the construction logistics structure.
3. **Facilitation**: The provision of infrastructure, public space, human resources, equipment or other resources such as calculation models for the construction logistics structure.
4. **Stimulation**: Providing financial and/or material incentives to stakeholders by rewarding construction logistics measures in permits or tenders. Stimulation can also be achieved by negative financial incentives.

The control options to influence the construction logistics structure vary per project phase (Quak et al., 2011). This thesis analyzed the control options in the preliminary construction and construction phase. Research of TNO proved that municipalities have the best opportunity to influence the construction logistics structure in the preliminary phases of a construction project (Quak et al., 2011). In these phases, market parties such as contractors, subcontractors and project developers can still be effectively influenced by the Municipality of Amsterdam. Table 19 illustrates which control options can be applied at which stage of a construction project. The yellow box indicates the phase in which the control option should be applied. Subsequently, the control options stated in the figure are explained below. Table 19 is based on a figure in the TNO research of Quak et al. (2011), but is modified to the control options for IJburg II. Other control options were found in the document of Gemeente Amsterdam (2020a).

Table 19: Control options Municipality of Amsterdam

	Preliminary construction	Construction
Regulate	Construction logistics criteria in permitting and tendering	
	Construction logistics guidelines in BLVC framework	
		Traffic measures
Coordinate	Setting up construction and consultation structure stakeholders to improve collaboration between stakeholders	
		Appointment of construction coordinator
Facilitate	Models for construction logistics	
	Rewarding construction logistics plans: providing infrastructure, public space for logistics operations, logistics personnel and transport vehicles	
Stimulate	Rewarding construction logistics plans: positive/negative financial incentives, immaterial incentives, privileges and subsidies	

As can be seen in table 19, the control options of the Municipality of Amsterdam are divided in four categories. These are ranked from top to bottom. The top control option is the most compelling or interfering instrument of the Municipality of Amsterdam, while the last control option is the most non-binding or least interfering instrument.

1. Regulate

- *Construction logistics criteria in permitting and tendering*: As the Municipality of Amsterdam is the client of the construction project IJburg II, it is able to impose strict requirements on the construction logistics structure in tenders and permits. This can be done via clear strategies and EMVI-criteria related to construction logistics and construction activities. These are, among others, criteria in the field of accessibility, nuisance, safety and environment.

- *Construction logistics guidelines in the BLVC kader*: The BLVC kader states agreements for construction on IJburg II. By expanding the rules and guidelines for construction logistics in the BLVC Kader, all parties are obliged to abide by the guidelines. However, these guidelines should be clear before the start of the construction activities.

- *Traffic measures*: The Municipality of Amsterdam can force parties to abide by traffic policies. These measures, such as preferred routes and time windows for construction traffic, can still be implemented during the construction process.

2. Coordinate

- *Setting up a construction and consultation structure*: This structure improves the collaboration between all stakeholders. The Municipality of Amsterdam should play an initiating and mediating role to involve all stakeholders. All actors should be engaged in the planning phase to discuss the planning, bottlenecks and challenges of the construction project. This prevents problems in a later stage. This consultation structure should be continued during the construction activities in order to identify problems in good time.

- *Appointment of construction coordinator*: A construction coordinator can be appointed by the Municipality of Amsterdam at the beginning of the construction project (or just before the beginning of the construction activities). The construction coordinator is responsible for overseeing the planning and is the contact point for all stakeholders.

3. Facilitate

- *Models for construction logistics*: The Municipality of Amsterdam can support construction logistics by facilitating models that measure the impact of construction logistics centres. These models show the effects of new construction logistics structures.

- *Rewarding construction logistics plans by facilitating measures*: The Municipality of Amsterdam is able to reward good construction logistics plans and logistics strategies of stakeholders. This can be done by providing infrastructure or public space for construction logistics centres. Public space can for example be facilitated by the Municipality of Amsterdam to store construction materials. Or, centres can be built and financed to make inter-modal transport possible. Furthermore, personnel can be hired to support extra transshipment activities or vehicles can be sold to perform sustainable material deliveries. These are far-reaching and costly measures and should therefore be carefully planned and worked out.

4. Stimulate

- *Rewarding construction logistics plans by stimulating measures*: The construction logistics structure can also be controlled with stimulating measures. A well-thought and efficient construction logistics plan can be stimulated with positive/negative financial incentives, immaterial incentives, privileges and subsidies. In this way, it becomes more attractive for stakeholders to participate in a more efficient and sustainable construction logistics structure.

7.5 Evaluation new construction logistics structures

In this subsection, the construction logistics structures that meet the new requirements, design 1 and design 3, are evaluated on the basis of stakeholders' perceptions. The evaluation was written on the basis of information from the stakeholder analysis and information gathered in exploratory conversations with multiple stakeholders such as the Municipality of Amsterdam, project developers and contractors. The perceptions of the following six stakeholders were evaluated: the Municipality of Amsterdam, contractors, project developers, road & waterborne freight transporters and new inhabitants of IJburg II. For the two new structures, it is discussed whether the stakeholders' interests are met and which issues stakeholders see in these structures. The described stakeholders' perceptions were reflected in the consultation group by assigning a stakeholder group to a member of the group and having that member evaluate the two designs from the perspective of that stakeholder group.

7.5.1 Construction logistics structure design 1

1. Municipality of Amsterdam

The Municipality of Amsterdam is positive about this construction logistics structure. First of all, the design complies to all need to haves of a construction logistics structure for IJburg II which indicates that most of the new ambitions in the field of construction logistics and construction activities are met. Furthermore, the structure can operate under the new stricter policy strategies and reduces the negative effects on the urban environment. In addition, the inclusion of waterborne transport is desired. The implementation is found challenging because multiple logistics centres have to be situated on IJburg II. This asks for investments in logistics centres and extra land reservations for the construction logistics structure on IJburg II. Due to the fact that construction materials are transported by water, the storage capacity on IJburg II should be rather large. Furthermore, the noise and visual nuisance caused by these structures is seen as a disadvantage. Another point of attention, is the necessity of a quay wall and a CCC outside IJburg after 2030 because this requires the rental of land outside of Amsterdam. Lastly, waterborne transport and use of construction logistics centres could potentially lead to extra transport costs. This would not be desirable. However, how high these additional costs are and how these costs potentially will be passed on in e.g. house prices is not investigated.

2. Contractors

The contractors find transportation by water for large non time-critical full-truckloads flows not desirable because this means that construction materials should be ordered a few weeks in advance. This lead to less flexible material deliveries what is unfavourable. In addition, the contractors cannot order heavy construction materials at suppliers who do not have access to waterborne transport. The implementation of a CCC and transshipment facility leads to less material deliveries and the possibility for JIT-deliveries which benefits the construction productivity. The contractors are supposed to participate in this construction logistics structure if the costs for storing and handling of construction materials on IJburg II will not be too high, if the material deliveries by water are punctual and if construction logistics centres are facilitated. In addition, the contractors wonder who should carry out the last-mile deliveries from the logistics centre to the construction site.

3. Project developers

The project developers fear a rise in costs due to for example waterborne transport and use of construction logistics centres. However, whether this is really the case and how this would affect the prices of houses should be examined in more detail. In addition, project developers see a risk in construction delays because of the transport by water. The project developers are supposed to participate in this structure if profits are still made on the development of the projects.

4. Road & waterborne freight transporters

Road freight transporters of mostly heavy non time-critical construction materials for the substructure and shell construction phase strongly oppose this structure, as their business is at risk. Road freight transporters supplying materials in the final phase are in favour of this structure, since material deliveries will be more flexible and faster due to the CCC. Moreover, the freight carriers do not have to enter IJburg II which saves a lot of time. However, the required investment in light electric vehicles is seen as a problem. Waterborne freight transporters are in favour of this construction logistics structure and are eager to participate, because their market share will increase. However, waterborne freight transporters emphasize that to enable waterborne transport, infrastructure such as a quay wall, transshipment equipment and in case of electric waterborne transport an electric pusher and quayside electricity for charging the pushers are required.

5. Inhabitants IJburg

The inhabitants support the new construction logistics structure because of positive effects on the urban environment such as the reduction in CO_2-, PM_x- and NO_x-emissions and less congestion. However, the visual and noise hindrance of the construction logistics centres on IJburg II and the high number of vehicle movements on IJburg II are seen as an disadvantage. Thereby, it must be stated that the inhabitants who live closest to the construction logistics centres will suffer the most inconvenience. However, the inhabitants will not oppose against this construction logistics structure.

7.5.2 Construction logistics structure design 3

1. Municipality of Amsterdam

Even though waterborne transport is not included in this design, the Municipality of Amsterdam is in favour of this construction logistics structure because it fulfills most of the ambitions related to construction logistics and construction activities. The logistics structure is able to operate under the new policy strategies and negative effects on the urban environment such as congestion and CO_2-, PM_x- and NO_x-emissions are reduced. Just as is the case for design 1, this structure also requires facilitation of construction logistics centres and extra space for these facilities on IJburg II. However, the required land has to be less than for design 1, as there will be no waterborne transport. This saves the space of a quay wall and extra storage capacity. Point of attention in this design is the need of logistics centres outside the city of Amsterdam. Both the centres for bundling at the source in the two time periods should be located outside the city boarders. The Municipality of Amsterdam finds this less attractive as the Municipality is less influential outside Amsterdam. Moreover, depending on the location of the suppliers and wholesalers multiple bundling centres are required.

2. Contractors

The contractors are positive about this new construction logistics structure. The non time-critical full-truckload flows do not have to be ordered in advance as is the case in design 1. This gives the contractors more flexibility. The decoupling point increases the number of JIT-deliveries and reduces the number of deliveries which leads to a higher labour productivity. However, the storage and handling costs for the decoupling centre should not be too high and last-mile deliveries from the logistics centres should be arranged.

3. Project developers

Project developers are supportive towards this construction logistics structure, because the construction time and quality of construction works will not suffer from this design. As there is no waterborne transport incorporated, the logistics structure is seen as less complex than design 1.

4. Road & waterborne freight transporters

Road freight transporters are partly satisfied with this design of a construction logistics structure, as waterborne transport is not incorporated. This gives road freight transporters a larger market share. However, this structure requires adaptations from road freight transporters. Less than truckload flows need to be bundled at logistics centres which requires cooperation and information sharing between freight transporters. These days, that is not common practice. In addition, the road freight transporters see the investments in electric vehicles as a problem. As no waterborne transport is included in this design, the perception of waterborne freight transporters are not evaluated.

5. Inhabitants IJburg

The inhabitants are positive about the new construction logistics structure because of the effects on the urban environment such as the reduction in CO_2-, PM_x- and NO_x-emissions and less congestion. However, two disadvantages are named. First, the high number of vehicle movements on IJburg II due to construction logistics. Second, the visual and noise hindrance of the construction logistics centres on IJburg II. However, these two disadvantages will not cause residents to oppose this structure.

7.6 Implementation plan construction logistics structure

After mapping the most important stakeholders in the construction logistics structure for IJburg II and identifying the stakeholders' perceptions towards the new designed logistics structures, the first steps towards an implementation plan could be taken. This subsection elaborates on the principles of an implementation plan for construction logistics structure design 1, as this design was identified as the most favourable structure by the Municipality of Amsterdam.

For an effective implementation plan, it is important to map which stakeholder has an interest in which issue/part of the new structure. The stakeholder-issue interrelationship diagram is a good tool for this purpose because it indicates which stakeholders have an interest in various issues, and how the stakeholders might be related to other stakeholders through their relationships with the issues (Bryson, 2004). Based on the results of this diagram, the Municipality of Amsterdam can establish a new construction logistics structure by specifically engaging stakeholders and applying effective control options. A stakeholder-issue interrelationship diagram was made for design 1 based on the evaluation in subsection 7.5. This evaluation revealed the issues that six stakeholder groups have with design 1.
The stakeholder-issue interrelationship diagram for design 1 is depicted in figure 22 and should give the Municipality of Amsterdam an idea which stakeholder groups need to be engaged in which topic. As can be seen in figure 22, the issues for implementation retrieved from the evaluation of design 1 in subsection 7.5 were summarized in 8 global issues. The issues are displayed in circles and the six stakeholder groups in squares. An arrow indicates that a stakeholder has an interest in that particular issue.

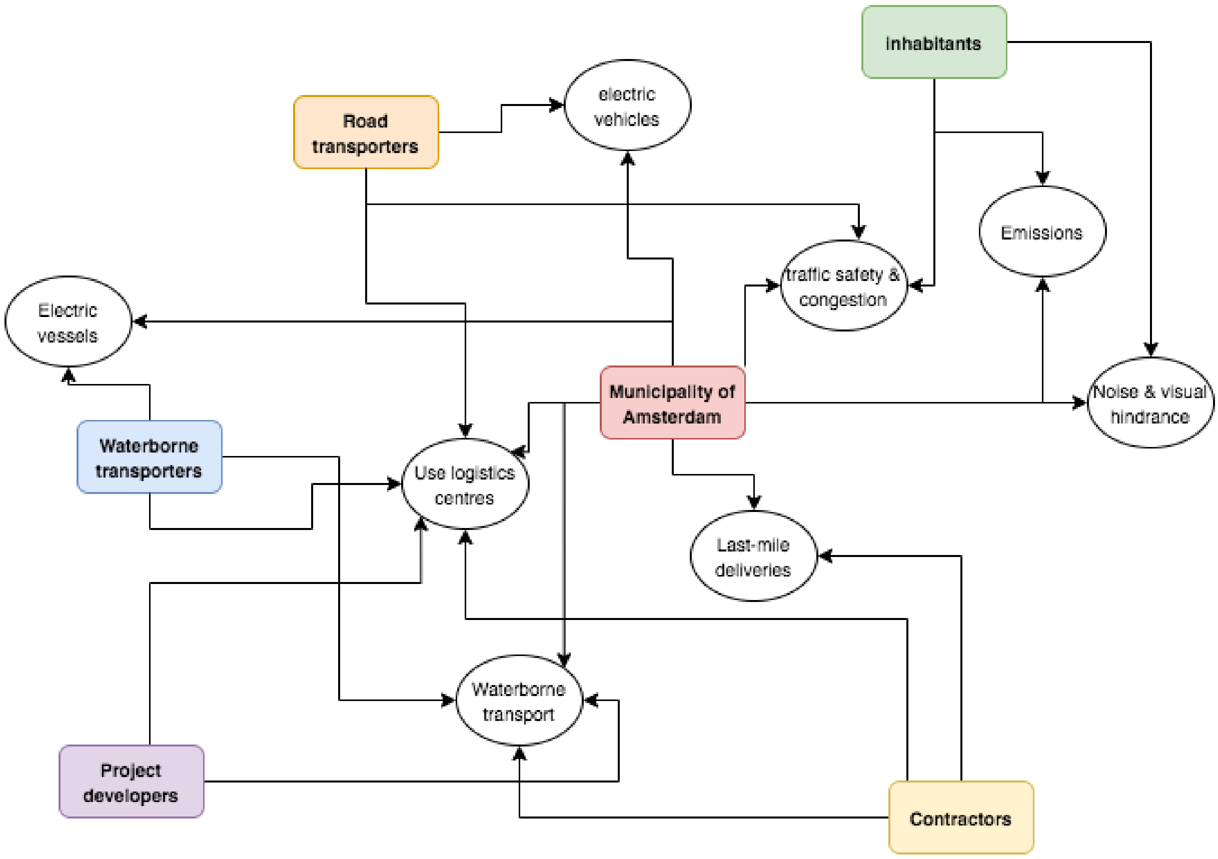

Figure 22: Stakeholder-issue interrelationship diagram for design 1

What can be concluded from figure 22 is that not every stakeholder has to be engaged in every issue for the implementation of construction logistics structure design 1. For instance, for the deployment of electric vessels, only waterborne transporters should be involved. While for electric last-mile deliveries, contractors should be engaged (out of these six stakeholder groups). This implies that the Municipality of Amsterdam should specifically involve stakeholders for establishing new structures. How these stakeholders should be influenced by the Municipality of Amsterdam through the use of control options or by incentives of other influential stakeholders should be examined next. In addition, it should be studied for more stakeholder groups, in which part of the construction logistics structure they have an issue. However, due to time limitations that is not included in this thesis.

7.7 Sub-conclusion

From the stakeholder analysis can be clearly stated that many stakeholders have a high interest and power in the construction logistics structure. The Municipality of Amsterdam is identified as the stakeholder with the highest power and interest because the Municipality is land owner and regulative power. In addition, the Municipality is responsible for a livable city which gives the Municipality a high interest in the construction logistics structure. Furthermore, two other influential stakeholders were identified: the project developers and stakeholders. What else can be concluded from this section is that the Municipality of Amsterdam has a number of control options to influence the construction logistics structure. These are regulating, coordinating, facilitating and stimulating measures. The number of control options are highest in the preliminary phase of construction activities.

The feasible construction logistics structures, design 1 and 3, were evaluated on the stakeholders' perceptions. The perceptions of the following six stakeholder groups were evaluated: the Municipality of Amsterdam, contractors, project developers, road & waterborne freight transporters and new inhabitants of IJburg II. From the evaluation can be concluded that the six evaluated stakeholder groups see some downsides in the feasible construction logistics structures related to their own interests. So, not every stakeholder group is equally positive about changing the construction logistics structure. Stakeholders have various problems with the impact of the structure on their own interests. Therefore, in order to establish a new structure, the Municipality of Amsterdam should specifically engage targeted stakeholders who feel impacted by the changing structure. A good implementation plan must be set up for this purpose.

8 Conclusion & Recommendations

The goal of this thesis was to design conceptual construction logistics structures for the Municipality of Amsterdam for the development of IJburg II. In this section, the thesis findings are presented first by answering and examining the research questions, research objectives and the thesis project objective. The thesis project objective was defined as follows:

To design conceptual construction logistics structures for residential and non-residential development on IJburg II that meet the new ambitions of the Municipality of Amsterdam related to construction logistics and construction activities.

After the thesis findings, the lessons learned from this study are presented. These are universal conclusions that were drawn from this research which also apply to similar construction projects as IJburg II. Thereafter, a critical reflection discusses some point of attentions of this report. Subsequently, recommendations for further research are provided. Last, recommendations are given to the Municipality of Amsterdam.

8.1 Thesis findings

In this subsection, the research questions and research objectives drafted in subsection 2.2 and the thesis project objective stated in subsection 1.5 are answered and examined. First the research question or objective is stated followed by the conclusion.

1. Which issues require a change in the construction logistics structure and how can the construction logistics structure be improved?

The construction industry is relatively slow with implementing new and dedicated logistics strategies for the transport of construction materials. This hinders improvements in the construction logistics structure and leads to an inefficient and outdated construction logistics structure. Due to the lack of improvements in the construction logistics structure in recent years and increasingly stringent requirements with regard to transport vehicles of municipalities, a number of problems have arisen in construction logistics. The four most notable issues for the construction logistics structure are: 1. the low efficiency and productivity of construction activities; 2. the low quality and efficiency of construction logistics; 3. negative impacts on the urban environment; and 4. the inability to comply to more strict transport strategies. In particular, the negative impacts on the urban environment and the inability to comply to new policy strategies are for municipalities a big problem and are therefore addressed by cities.

Multiple solutions can be applied to improve the construction logistics structure. A good solution is the construction logistics centre. A construction logistics centre is a contact point of multiple transportation types where the distribution of freight flows is concentrated and performed. The construction logistics centre is a good improvement for the construction logistics structure because it can fulfill multiple functions in a logistics system and lead to better organised construction logistics flows. This allows all construction material flows to be supported by a construction logistics centre.

2. How will the construction activities on IJburg II be developed and which strategies and ambitions of the Municipality of Amsterdam in the field of construction logistics and construction activities need to be taken into account in the construction logistics structure?

The construction activities on IJburg II will take place from 2020 until 2038. First, Centrumeiland will be constructed followed by Strandeiland. However, there will be an overlap in construction activities for the two islands. In principle, the construction activities shift from west to east across the islands, with a few exceptions. For the majority, the construction activities exist of residential development but there will also be some non-residential development. All the four construction phases must be completed on IJburg II, as it is an urban development project.

The Municipality of Amsterdam stimulates the use of circular construction materials on IJburg II. From 2030, 50% of the used construction materials for construction activities should be circular. Therefore, it can be concluded that there will be a shift in material usage from conventional construction materials to circular construction materials during the construction activities. The construction techniques that can be used on IJburg II are limited in particular by the rules on low-noise and low-vibration construction techniques. This means that the construction technique to drive piles is not possible. In addition, it can be concluded that construction activities shift from the construction site to factories during the construction period of IJburg II due to the industrialisation of the construction process.

Four policy documents of the Municipality of Amsterdam state relevant ambitions and strategies related to construction logistics: Actieplan Schone Lucht, Nota Varen Deel 2, Agenda Amsterdam Autoluw and BLVC-kader IJburg II. Important ambitions for construction logistics are ambitions related to the CO_2-, PM_x- and NO_xemissions, improvement of traffic safety, increase in waterborne freight transport and reduction of congestion. Strategies that need to be taken into account are emission-free road and waterborne transport from 2030 on and around IJburg II and restricting emission standards for road vehicles.

3. What are requirements of a construction logistics structure for IJburg II?

The requirements of the construction logistics structure were based on the ambitions of the Municipality of Amsterdam related to construction logistics and construction activities. A total of nine need to haves (and four sub need to haves) and six nice to haves were identified for the construction logistics structure for IJburg II. In section 4, the need to haves are depicted in table 3 and the nice to haves in table 4. In addition, it was concluded that the preconditions that limit the design space for the logistics structure change in 2030 due to the emission-free strategy on and around IJburg II.

4. To design conceptual construction logistics structures for IJburg II.

Seven types of construction logistics centres can improve the construction logistics structure for IJburg II. These seven logistics centres are: 1. centre for bunding at the source; 2. construction consolidation centre; 3. decoupling centre for road transport; 4. centre for production at the site; 5. buffer centre; 6. centre for collection waste; and 7. transshipment centre for inter-modal transport. However, it can be concluded that not every type of construction logistics centre can be applied to any of the six generated construction material flows for the development of IJburg II. Therefore, table 5 in subsection 5.2.1 states which construction logistics centre can be applied for which flow. From this, it can also be concluded that not every construction logistics centre is applicable in every construction phase which can be seen in table 6 in subsection 5.3.

Construction materials are transported by one mode (uni-modal) or multiple modes (multi-modal). In multi-modal transport and transport with different vehicle types, transshipment should be taken into account. Transport of construction materials by road can be performed by different vehicle types. The best vehicle type depends on the type of cargo. Construction materials by water are transported by push barge. Electric vehicles and vessels are on the rise for both road and waterborne transport. However, for both modes of transport, the transport of heavy construction materials over long distances is not yet feasible. Transport over shorter distances with heavy construction materials or longer distances with light construction materials is achievable. Last-mile transport of construction materials on IJburg II can be performed in different ways: conveyor belt, light truck, van or rail system.

Three designs of construction logistics structures for IJburg II were drafted. First, designs were generated for the subsystems of the construction logistics structure. These subsystems are the generic construction material flows. The new designs of subsystems were developed with construction logistics centres and new transport types for construction logistics. Per subsystem, designs were made for the time period till 2030 and for the time period after 2030 due to the change in applicable preconditions. Thereafter, three construction logistics structures were composed by combining several designs of subsystems. Only three new structures for IJburg II were created due to time limitations. However, many more can be made out of this thesis. The three new designs are explained and displayed in subsection 5.3.

5. To test the conceptual construction logistics structures on the new requirements.

The designs needed to be tested on the requirements both qualitatively and quantitatively. The qualitative test was carried out by checking whether the requirement was present in the design of the new construction logistics structure or not. The quantitative test consisted of a newly developed calculation model. This model calculates the vehicle movements and the CO_2-, PM_x- and NO_x-emissions for the new construction logistics structures. Logistics data of a reference construction project and a number of assumptions were used to develop this model. The outcomes of the models showed significant reductions of emissions for all three new designs. In addition, the results of the designs displayed a high decrease of required transport towards IJburg II, but an equal amount or even small increase of vehicles on IJburg II. The three designs were tested on the requirements in the design verification. The need to haves were tested binary, while scores were used for the nice to haves. From the design verification can be concluded that two of the three designs, design 1 and 3, fulfill the need to haves (minimal requirements). Out of the two designs that comply to the need to haves, design 1 scores best on the nice to haves due to the inclusion of waterborne transport and a higher decrease of congestion by construction logistics movements.

6. To evaluate the feasible construction logistics structures on the stakeholders' perceptions.

The feasible construction logistics structures, design 1 and 3, were evaluated on the stakeholders' perceptions. The perceptions of the following six stakeholder groups were evaluated: the Municipality of Amsterdam, contractors, project developers, road & waterborne freight transporters and new inhabitants of IJburg II. From the evaluation can be concluded that the six evaluated stakeholder groups see some downsides in the feasible construction logistics structures related to their own interests. So, not every stakeholder group is equally positive about changing the construction logistics structure. Stakeholders have various problems with the impact of the structure on their own interests. Therefore, in order to establish a new structure, the Municipality of

Amsterdam should specifically engage stakeholders who feel impacted by the changing structure. A good implementation plan must be set up for this purpose.

To design conceptual construction logistics structures for residential and non-residential development on IJburg II that meet the new ambitions of the Municipality of Amsterdam related to construction logistics and construction activities.

The three new designs of a construction logistics structure for IJburg II were qualitatively and quantitatively tested on the drafted requirements in subsections 4.2 and 4.3. Out of the design verification can be concluded that two of the three new designs, design 1 and 3, meet the need to haves of a construction logistics structure for IJburg II. Design 2 is not suitable as structure, because it does not meet the requirement of a 25% CO_2-reduction due to construction logistics movements. This conclusion means that the thesis project objective was achieved, as two new conceptual designs of a construction logistics structure for IJburg II meet the new requirements based on the ambitions of the Municipality of Amsterdam in the field of construction logistics and construction activities.

8.2 Lessons learned

As described in subsection 1.3, the addressed problem in this thesis is not unique for IJburg II. This means that solutions found and conclusions drawn in this study can also apply to other projects in the Netherlands. The universal lessons learned in this thesis on construction logistics structures for urban development projects are presented below. In addition, the last two points indicate how the thesis approach can help municipalities in the decision-making process of new construction logistics structures for equivalent urban development projects.

- A significant reduction of CO_2-, PM_x- and NO_x-emissions can be achieved by changing the construction logistics structure by implementing construction logistics structures and new types of transport.
- A significant reduction of vehicle movements from suppliers or wholesalers to the construction site or construction logistics centre can be achieved due to the implementation of construction logistics centres and new types of transport.
- The deployment of smaller electric vehicles for last-mile deliveries from one or more construction logistics centres to the construction site slightly increase the number of vehicle movements for last-mile deliveries.
- Construction logistic centres lead to better organized construction logistic flows even if the construction material flow not physically pass through the centre.
- The applicable construction logistics centre for an urban development project depends on the characteristics of the construction material flows.
- Construction logistics centres for waterborne and road transport are required at the edges of emission-free (environmental) zones as long as heavy trucks and push barges are not fully electric and available in large numbers. This is where the transshipment of construction materials from diesel vehicles to electric vehicles must take place.
- Before a feasible construction logistics structure can be designed, the ambitions and strategies of municipalities with regard to construction logistics must be clear and unambiguous.

The thesis approach for other urban development projects:

- For this thesis, the engineering design process was used. This approach is a suitable method for designing feasible construction logistics structures that should meet new requirements. The study focused on sustainable requirements set by the Municipality of Amsterdam, but this approach can also be used to come up with designs from a more economic or efficiency point of view.
- The drafted designs of subsystems in the study can be used by municipalities to create new construction logistics structures for comparable urban development projects. These structures can then be tested on the ambitions. So, the thesis gives municipalities a tool to decide about the most suitable construction logistics structure based on their ambitions.

8.3 Reflection

In this subsection, a critical reflection is given on this thesis which puts the research in the right perspective. A number of comments and points of attention are discussed.

This thesis focused on designing construction logistics structures for residential and non-residential development on IJburg II. Urban development also often involves the development of infrastructure, these construction activities are not considered in this research. It could be that when this type of development was taken into account, different construction logistics structures were designed. However, a number of the construction materials required for the development of infrastructure are similar to the construction materials used in the site preparation and substructure construction phase which implies that the new designed construction logistics structure would largely be suitable for the transportation of these construction materials.

The construction logistics structures developed are based on strategies and ambitions of the Municipality of Amsterdam that are now known to apply to IJburg II. Shifts in the ambitions and strategies would have a great influence because it would change the requirements for the logistics structure for IJburg II. This could mean that designs that now comply to all the requirements, suddenly no longer meet the requirements. That is why, it is important for the Municipality of Amsterdam to first clearly state the ambitions and strategies before designing new structures. The two designed feasible construction logistics structures specifically meet the ambitions and strategies stated in this research. In addition, this thesis does not give an optimal new construction logistics structure for IJburg II but gives the Municipality of Amsterdam a tool to design new structures by means of implementing new types of transport and construction logistics centres. Therefore, the report could also be used by other municipalities for designing construction logistics structures of equivalent urban development projects.

To achieve ambitions related to the reduction of emissions it is important that the strategies devised by the Municipality of Amsterdam are feasible, both technically and legally. The logistics structures are namely designed with the idea that these strategies can be implemented. If these strategies cannot be implemented, the ambitions will not be achieved. The legal feasibility of completely emission-free transport on IJburg II and the technological feasibility of a good functioning electric charging infrastructure on IJburg II should be for example critically evaluated. This reduces the chance for the Municipality of Amsterdam of not achieving the ambitions.

As stated in subsection 6.2, the calculation model used to calculate the vehicle movements and the vehicle emissions contains a number of assumptions and uncertainties. This means that the outcomes of the model are only valid when these assumptions apply. For example, a change in construction time or construction method would change the results of the model. However, the results differ not significantly which means that the drawn conclusions regarding the reductions of vehicle movements and vehicle emissions are still valid. Due to a lack of data, the vehicle movements could not be calculated into detail. This also applies for the vehicle emissions, as these are calculated by means of the vehicle movements. However, for the scenario described in this report, the model gives a good indication of the number of vehicle movements and the amount of vehicle emissions per design. Important to note is that the vehicle emissions are calculated with well-to-wheel emission factors. As a result, not only actual vehicle emissions were considered, but also the emissions needed to for example generate electricity or produce fossil fuels. If only tank-to-wheel emissions were taken into account, the emission reductions could perhaps be higher. The used emission factor has thus a great influence on the calculated emissions.

The focus of the thesis was more on designing new construction logistics structures than on evaluating the designs. The new developed designs were therefore not evaluated into detail, but only on the stakeholders' perceptions. If an actual implementation of one of the structures is desired, a more extensive evaluation is required because this study only emphasizes the environmental and social benefits but not the costs. The evaluation should include factors such as costs, safety and performance. Only when the feasible designs have been evaluated on all factors, the Municipality of Amsterdam can make a well-considered decision whether or not a structure is suitable for implementation.

8.4 Recommendations for further research

A number of research gaps arose from this thesis. In this subsection, the research gaps are used as directions for further research. Three directions for further research are listed below.

1. This thesis focused on construction logistics structures for residential and non-residential development on IJburg II. However, another large part of construction activities for urban development projects, the development of infrastructure, was not included. Therefore, the first recommendation for future research will be to design construction logistics structures for infrastructural development in urban development projects. After the study, the structures can be compared to see if the structures match on points.

2. The reflection stated that before well-considered decisions can be made about new construction logistics structures, not only the benefits should be studied but also the costs. Hence, the second direction for future research is to study the costs for construction logistics structures as proposed in this thesis. In addition, when the costs are clarified potential business models can be studied for construction logistics centres in the new structure.

3. What came forward in this study was that cooperation of multiple stakeholders is required in order to implement new construction logistics structures. Therefore, it would be interesting to investigate how and when stakeholders are willing to participate in new logistics structures. In addition, it can be studied how municipalities should contribute to these structures in order to achieve their ambitions.

8.5 Recommendations to Municipality of Amsterdam

In this subsection, the recommendations for the Municipality of Amsterdam are given based on the study. First the recommendation is stated followed by the explanation.

1. First look at ambitions, then at strategies and finally at new construction logistics structures

The Municipality of Amsterdam has multiple ambitions in the field of construction and construction logistics. At the moment, some of these ambitions are not clear. This lead to a lack of clarity for all parties involved and could lead to various interpretations. For example, what is exactly meant with the term emission-free? Therefore, it is advised to redefine these ambitions once more with the stakeholders within the Municipality. Once the ambitions are clear, strategies can be developed to achieve these ambitions. In addition, it should be investigated if these ambitions and strategies lead to the desired result. Two examples:

1. The requirement to build low-noise and vibration-free prevents pile driving. However, from a logistics point of view it is more sustainable to transport prefab piles than ready-mixed concrete for in-situ cast concrete piles.
2. The ambition of a reduction in vehicle movements on IJburg II can lead to a more polluting construction logistics structure because heavier, more polluting trucks are required to fulfill this ambition.

Finally, when the ambitions and strategies are clarified, effective construction logistics structures can be designed that meet the ambitions and strategies.

2. Conduct additional studies to eliminate uncertainties for construction logistics structure

A number of aspects need to be considered in order to come up with an effective construction logistics structure for IJburg II. A lot of these aspects are still uncertain for the construction project IJburg II. These are, among others, the to be used construction techniques and construction materials; the availability of new transport types, the willingness to use construction logistics centres of stakeholders and the available space for construction logistics centres on IJburg II. A better-considered decision can be made for a construction logistics structure if these uncertainties are eliminated.

3. Focus on suitable solutions per construction phase or construction material flow not on a one-size-fits-all solution

The thesis made clear that not every construction logistics solution is applicable on all construction material flows. There is no such thing as a one-size-fits-all solution for construction logistics. The idea that a 'bouwhub' could solve most of the problems related to construction logistics has to change.

4. Design and evaluate other construction logistics structures for IJburg II utilizing this thesis approach

Many more construction logistics structure designs for IJburg II can be made by combining designs of subsystems that are drafted in this thesis. This report can thus be used as a tool for the Municipality of Amsterdam to find the best new construction logistics structure. The thesis itself does not give the optimal solution but mainly shows how to find a suitable structure that meet the new ambitions of the municipality.

5. Extend the calculation model with infrastructural development for IJburg II

The developed calculation model now only estimates the vehicle movements and vehicle emissions for residential and non-residential development on IJburg II. This calculation model can be extended with infrastructural development to get a better picture of the total scope of construction logistics for IJburg II. However, it should be noted that the model presents rough estimates and not exact numbers. In order to calculate the vehicle movements and vehicle emissions for new construction logistic structures, it will first be necessary to study which construction material flows are generated in infrastructural development and which logistics centres can be used for these flows.

6. Continue this study where it left off for an implementation plan

The study stopped at giving an insight into which stakeholders have an interest in which issue of a new construction logistics structure. However, this has only be done for a number of stakeholders and not on a detailed scale. For an implementation plan of a new logistics structure, it is necessary to examine all the stakeholders and to go even deeper into possible problems of stakeholders with a new structure. On the basis of these outcomes, it can be evaluated how stakeholders should be engaged and which control options, if any, should be deployed. In addition, what is important to remember for the Municipality of Amsterdam that it has the most control options in the preliminary phases of a construction project.

Next to that, it is important to evaluate construction logistics structures into more detail. The designs are now only evaluated on the stakeholders' perceptions. Costs, performance, safety and required land are other factors that should be studied, before moving on to implementation.

7. Other recommendations

- Research if construction logistics centres can contribute to the circular ambitions of the Municipality of Amsterdam. It seems that these logistics centres can be used for the storage of circular materials on the islands, but this should be explored in more depth.
- Due to the current intended strategy of the Municipality of Amsterdam for an emission-free environmental zone from 2030 for the whole city Amsterdam, construction logistics centres are necessary at the edges of the city for decoupling purposes of polluting transports. This will not only apply for the urban development project IJburg II, but also for other construction projects in Amsterdam. A municipality-wide approach to tackle this issue seems more appropriate than a project-wide approach.

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A Scientific paper

The Development of Construction Logistics Structures
Case IJburg II

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***Abstract*—Construction logistics has a negative impact on the urban environment. Therefore, in this study, construction logistics structures are designed for residential and non-residential development that should reduce the negative effects of construction-related transport in cities. These structures were made for the urban development project IJburg II in Amsterdam and were designed on the stricter requirements for construction logistics and construction activities drawn up by the Municipality of Amsterdam. To design these new construction logistics structures, the engineering design process was used. The requirements of the new structure were identified by means of a case study to the development project IJburg II. The new designs of subsystems were generated with applicable construction logistics centres and new types of transport derived from literature. This led to several new designs for subsystems. Out of these subsystem designs, three new construction logistics structures for IJburg II were developed. The three structures were tested both quantitatively and qualitatively on the new requirements which showed that two of the three structures fulfill the new standards. For the quantitative test, a calculation model was developed that calculates the vehicle movements and vehicle emissions for each design. The results of this calculation model indicated that all three designs significantly decrease the CO_2-, PM_x- and NO_x-emissions and vehicle movements to and from IJburg II. The last-mile deliveries, however, remain unchanged or even slightly increase due to the deployment of light electric vehicles. The research proved that by changing the construction logistics structure, significant vehicle emission reductions can be achieved. In addition, a reduction of vehicle movements to and from construction sites can be established but will in most cases lead to slightly more last-mile deliveries. However, stakeholders need to be specifically engaged to enable implementation of these new structures. Last, this study demonstrated that the engineering design method is a suitable approach to design new construction logistics structures.**

Keywords: Construction logistics , construction logistics structures, urban development projects, construction logistics centres, design approach, negative impact urban environment, CO_2-, PM_x- and NO_x-emissions

I. Introduction

At this moment, the Dutch housing market is struggling with major houses shortages [1]. The housing shortage is a problem throughout the Netherlands, but the situation is particularly acute in large cities. This implies that new urban development projects are required in the upcoming years to overcome the housing shortage. Urban development consists of residential, non-residential and infrastructural development. However, infrastructural development was not included in this research. The new urban development projects generate construction material flows. Construction-related transport is the most polluting source of all freight transport in a city [2]. Therefore, well-organised logistics is required to manage these transport flows. The term construction logistics is used for the management of construction-related flows. Thus, construction logistics involves the planning, organisation, coordination and control of the construction material flows from the extraction of raw materials to building site [3]. Recycle or waste flows are also included [4].

At the moment, however, construction logistics leads to a number of problems: additional costs in the construction process, a poor quality of construction works, longer project times and negative impacts on the urban environment [5] [6] [7] [8]. A number of proven negative externalities of construction logistics on the urban environment are the increase in congestion, the decrease of road safety and the higher amount of noise and air pollution [9]. This indicates that a change in the construction logistics structure is required to counteract the negative effects. Change is not only necessary from this point of view, but also because municipalities are imposing increasingly stringent requirements regarding transport vehicles. The construction industry has so far been unable to change the construction logistics structure to address these problems. This is mainly caused by the low level of cooperation between the large number of stakeholders in construction logistics [7].

The problem of housing shortage also occurs in Amsterdam and has invoked numerous urban development projects. One of these urban development projects is IJburg II. The construction of IJburg II will increase the amount of construction-related transport to, in and from Amsterdam. The Municipality of Amsterdam is one of the municipalities that imposed more stringent requirements with regard to transport vehicles and has high ambitions to reduce the negative effects on the urban environment in particular on air quality. The Municipality of Amsterdam expects that the construction industry will not come up with a solution of its own and thinks that drawing up stricter strategies for construction logistics alone will not lead to the achievement of the new ambitions related to construction logistics. In addition, the Municipality of Amsterdam wants to be assured of smooth construction logistics in the future, also under the stricter strategies. That is why, the Municipality of Amsterdam itself wants to think about new construction logistics structures. However, the Municipality does not know how this new structure should like because to date, these construction logistics structures are not identified. Therefore, designs should be made to explore the possibilities of new construction logistics structures that comply to the new requirements.

Therefore, this paper has the following design objective:

To design conceptual construction logistics structures for residential and non-residential development on IJburg II that meet the new ambitions of the Municipality of Amsterdam related to construction activities and construction logistics.

The above described problem of the Municipality Amsterdam is not unique for the development of IJburg II. Other equally sized urban development projects, between the 5.000 and 15.000 houses with some non-residential development, will face the same issues as IJburg II. These projects can either be urban development projects or urban transformation projects. Examples of such projects in The Netherlands are: Buiksloterham, Amstel III, Hamerkwartier (all three situated in Amsterdam), Binckhorst (The Hague) and Stadionpark (Rotterdam). This means that solutions found and conclusions drawn in this research can also apply to these projects.

This paper is structured as follows. Section II provides relevant background information to this study. Section III discusses the methodology. Section IV presents the case study to the development project IJburg II. Section V describes the new requirements. Section VI explains the design process. Section VII discusses the calculation model and the design verification. Section VIII elaborates upon the evaluation of the new structures. Last, Section IX provides the conclusions, reflection and recommendation for further research.

II. Background

This section provides relevant background to this study by covering a number of topics. First, the construction phases for residential and non-residential development are explained, followed by the generic construction material flows. Last, the concept of a construction logistics centre is presented.

A. Construction phases

The construction activities for residential and non-residential development can be roughly divided in four construction phases. The four construction phases are depicted in figure 1 and are explained below:

1) *The construction site preparation:* the construction phase of machining the ground level to enable construction activities. This phase could include construction activities such as excavating, heightening and pre-loading the ground.
2) *The substructure construction:* the phase in which the foundation will be constructed for the new structures.
3) *The shell construction:* the construction of the shell. At the end of this stage, the framework is wind- and waterproof.
4) *The final construction:* the construction phase in which the building is to be completed. This stage is characterized by mostly indoor construction activities. After the final construction phase, the structure is ready for delivery.

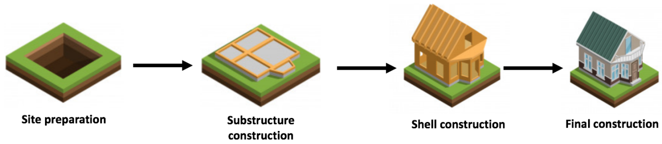

Fig. 1: The four construction phases

B. Construction material flows

This study focuses on the transport of construction materials, as these flows have a high impact on the urban environment. Six generic construction material flows for construction projects can be distinguished [10]. The main characteristics of these six flows and how these are currently being transported are described below:

1) *Large time-critical full-truckload flows:* these are 'thick' full-truckload flows of construction materials with a time-critical element directly delivered to the construction site. However, the return trip is empty transport. An example of such a flow is ready-mixed concrete. Ready-mixed concrete is time-critical because concrete starts to cure after some time, even in a concrete truck. This type of flows cannot be bundled due to the time-critical element. Transport takes place form supplier to construction site
2) *Large non time-critical full-truckload flows:* these are also 'thick' full-truckload flows directly delivered to the construction site. Again, the return trip is empty transport. The flows mostly comprise of materials used for the substructure and shell construction (ruwbouw) such as piles, sand, gravel, insulation material, sand-lime bricks, wood, iron and metal. Transport takes place from the supplier or wholesaler to the construction site in a heavy truck
3) *Non time-critical small less than truckload flows:* these are the smaller flows of construction materials. The load factor of the transport vehicle is less than truckload which means a low load factor. Transport vehicles used for this type of flow are heavy or light trucks. These flows mostly consist of construction materials delivered on pallets such as glass, paint, installation materials and plasterboards. This type of flows are mainly generated in the final construction phase and originate from multiple suppliers and wholesalers.
4) *Non time-critical packages:* these are the smallest flows of construction materials. These deliveries to the construction site are much smaller than the non time-critical less than truckload flows. These flows are often transported in light trucks or vans. The load factor of the transport vehicle is low. This flow type is mainly generated in the final construction phase and originates from multiple suppliers and wholesalers.
5) *Time-critical rush orders:* this is the time-critical flow for the smallest construction materials. Transport mostly takes place by light truck or van and the load factor is extremely low. These flows are frequently caused by flaws in the planning or miscommunication between supplier and customer. This flow mostly occurs in the

final construction phase and can be sent from multiple suppliers and wholesalers. Delivery should take place within a day to avoid delays in the construction process.

6) *Reverse flows:* these are all the flows transported in opposite direction from the construction site. There is a large variety in flows in this category as it is used as a collection group for all reverse flows. The flows are always non time-critical but can be both full-truckload or less than full-truckload depending on the type of waste. Transport vehicles arrive empty at the construction site and the return trip is full-truckload. The reverse flows can consist of all kinds of construction materials depending on the construction phase. The reverse flows during site preparation will be primarily sand, while the waste during the final construction phase mainly consists of plastic and cardboard. The reverse flows are transported in containers or bulk to a waste disposer in different sizes of transport vehicles.

C. Construction logistics centre

The construction logistics centre is widely seen as an attractive solution to improve the construction logistics structure because it can support the logistics structure with multiple functions [11]. Literature explains the generic definition of a logistics centre in two ways [12]. First, as a part of the transportation infrastructure. The logistics centre is in this case a contact point of various transportation modes and vehicle types (with different capacity) where the distribution of freight flows is concentrated and performed. Material flows can for example be decoupled or consolidated in a logistics centre and be distributed from there. Thereby, it stimulates intermodal transportation, serves a wide range of clients with value added services and presents new technological services [12] [11]. Second, as a generator for business. In this sense, the logistics centre does not focuses mainly on the transportation activities but is used as a tool to improve the logistics services [12]. This paper assumes the first meaning.

The configuration of a construction logistics centre can be adjusted in multiple ways enabling various functionalities in the construction logistics structure such as: storage, transport, distribution, consolidation, decoupling, assembly, production, and management of distribution network and vehicle routing [11]. Especially the coordination function of a construction logistics centre is interesting because this implies that although the main function of a logistics centre is not applicable for a certain flow type, the coordination can still be done via this logistics centre. In addition, the specific functionalities a construction logistics centre needs, depends on the requirements of the construction logistics structure [11]. The implementation of logistics centres is a far-reaching measure to intervene in the construction logistics structure. That is why, this measure type is not relevant for small construction projects of for example 100 houses but has its added value for larger urban development and transformation projects.

III. Methodology

The engineering design approach was partly used for this study to create conceptual designs of the construction logistics structure for IJburg II [13]. The engineering design approach can be generally divided into five steps of which three active design phases [13]. The five steps in the engineering design approach are:

1) Problem definition: the stage in which the problem is framed by clarifying the client's problem statement, objectives, requirements and preconditions
2) Conceptual design: the generation of different concepts to achieve the objective
3) Preliminary design: the examination and evaluation of preliminary choices
4) Detailed design: the refinement of choices made in the preliminary design
5) Design communication: the step to communicate the design, findings and conclusions

As the goal is to design conceptual designs of a construction logistics structure, the fourth step of the engineering design process was not performed in this study. Furthermore, some steps were added to the design engineering process in order to achieve the thesis project objective. Therefore, the design engineering process was adjusted for this research.

The design approach used to develop the construction logistics structure was as follows. First, the project IJburg II was analysed on construction phases and construction flows by means of a case study. The case study revealed a number of relevant aspects of the project IJburg II such as the building characteristics, the construction sequence, the to be used construction materials and techniques, and the generated construction material flows. Furthermore, the ambitions and strategies of the Municipality of Amsterdam related to construction logistics and construction activities for IJburg II were identified by means of document analyses.

Second, the gathered information in the case study was used to define the design requirements and preconditions. These requirements and preconditions were thus drafted from the point of view of the Municipality of Amsterdam. The requirements were divided in need to haves (constraints) and nice to haves (objectives).

Third, designs for subsystems of the construction logistics structure were generated in the design synthesis based on the system requirements and preconditions. The new subsystems designs were generated with applicable construction logistics centres and new types of transport derived from literature. This led to several new designs for subsystems of the construction logistics structure. From these subsystem designs, three new construction logistics structures for IJburg II were developed.

Fourth, The three developed construction logistics structures were tested against the earlier drafted requirements both qualitatively and quantitatively. The requirements were tested quantitatively by means of a newly developed calculation model in Microsoft Excel. This model calculates the vehicle movements and the CO_2-, PM_x- and NO_x-emissions for each design.

IV. Case study IJburg II

The construction activities on IJburg II will take place from 2020 until 2038. First, Centrumeiland will be constructed followed by Strandeiland. However, there will be an overlap in construction activities for the two islands, as the construction activities for Strandeiland start in 2023 and the construction activities for Centrumeiland last until 2025. In principle, the construction activities shift from west to east across the islands, with a few exceptions. For the majority, the construction activities exist of residential development but there will be also a little non-residential development. All the four construction phases must be completed on IJburg II, as it is an urban development project.

The Municipality of Amsterdam stimulates the use of circular construction materials on IJburg II. From 2030, 50% of the used construction materials for construction activities should be circular. Therefore, there will be a shift in material usage from conventional construction materials to circular construction materials during the construction activities. The construction techniques that can be used on IJburg II are limited in particular by the rules on low-noise and low-vibration construction techniques. This means that the construction technique to drive piles is not possible. In addition, it is expected that construction activities shift from the construction site to factories during the construction period of IJburg II due to the industrialization of the construction process.

Four policy documents of the Municipality of Amsterdam state relevant ambitions and strategies related to construction logistics: Actieplan Schone Lucht, Nota Varen Deel 2, Agenda Amsterdam Autoluw and BLVC-kader IJburg II. Important ambitions for construction logistics are ambitions related to the emissions of CO_2-, PM_x- and NO_x, improvement of traffic safety, increase in waterborne freight transport and reduction of congestion. Strategies that need to be taken into account are emission-free road and waterborne transport from 2030 on and around the IJburg II and restricting emission-standards for road vehicles.

V. Requirements Construction Logistics Structure IJburg II

Based on the findings in the case study, requirements and preconditions were specified for the new construction logistics structure for IJburg II. The design preconditions specify the elements that limit the design solutions. This could be factors such as environmental limits, legislative and regulatory standards [14]. A requirement is a statement that indicates a capability or function needed by a system in order to satisfy a customer need [15]. A requirement should state what the system has to do, but should not indicate how the system has to do it [15]. Two types of system requirements can be distinguished: the mandatory requirements (also called constraints) and trade-off requirements (also called objectives) [15]. Both requirements are used in this paper. The mandatory requirements, from now on referred to as *need to haves*, define the necessary capabilities that a system must have in order to be acceptable. The trade-off requirements, from now on referred to as *nice to haves*, specify capabilities that would make the customer happier [15]. A total of nine need to haves (and 4 sub need to haves) and 6 nice to haves were identified and defined for the new construction logistics structure. In addition, it was found that the preconditions for the new structure change in the year 2030 due to the emission-free strategy for transport vehicles on IJburg II.

VI. Design Construction logistics structures IJburg II

Seven types of construction logistics centres can improve the construction logistics structure for IJburg II. These seven logistics centres are: 1. centre for bunding at the source; 2. construction consolidation centre; 3. decoupling centre for road transport; 4. centre for production at the site; 5. buffer centre; 6. centre for collection waste; and 7. transshipment centre for inter-modal transport. However, not every type of construction logistics centre can be applied to any of the six generated construction material flows for the development of IJburg II. Therefore, table I states which construction logistics centre can be applied for which construction material flow. A cross in the box indicates that the logistics centre can be used for this type of construction flow.

TABLE I: Possible construction logistics centres per generic construction material flow

	1. Centre for bundling at the source	2. Construction consolidation centre	3. Decoupling centre for road transport	4. Centre for Production at the site	5. Buffer centre	6. Centre for Collection waste	7. Transshipment centre for intermodal-transport
Large time-critical full-truckload flows				x			
Large non time-critical full-truckload flows			x		x		x
Non time-critical small less than truckload flows	x	x					
Non time-critical packages	x	x					
Time-critical rush orders		x					
Reverse flows						x	x

Construction materials are transported by one mode (unimodal) or multiple modes (multi-modal). In multi-modal transport and transport with different vehicle types, transshipment should be taken into account. Transport of construction materials by road can be performed by different vehicle types. The best transport type depends on the type of cargo. Construction materials by water are transported by push barge. Electric vehicles and vessels are on the rise for both road and waterborne transport. However, for both modes of transport, the transport of heavy construction materials over long distances is not yet feasible. Transport over shorter distances with heavy construction materials or longer distances with light construction materials is achievable. Last-mile transport of construction materials on IJburg II can be performed in different ways: conveyor belt, light truck, van or rail system.

Three designs of construction logistics structures for IJburg II were drafted. First, designs were generated for the subsystems of the construction logistics structure. These subsystems are the generic construction material flows. The new designs of subsystems were developed with construction logistics centres and new transport types for construction logistics. Per subsystem, designs were made for the time period till 2030 and for the time period after 2030 due to the change in applicable preconditions. Thereafter, three construction logistics structures were composed by combining several designs of subsystems. Only three new structures for IJburg II were created due to time limitations. However, many more can be made out of this study. The three new designs are illustrated in figures 2, 3 and 4. The top structure is for the time period 2020-2029 and the bottom structure for 2030-2038.

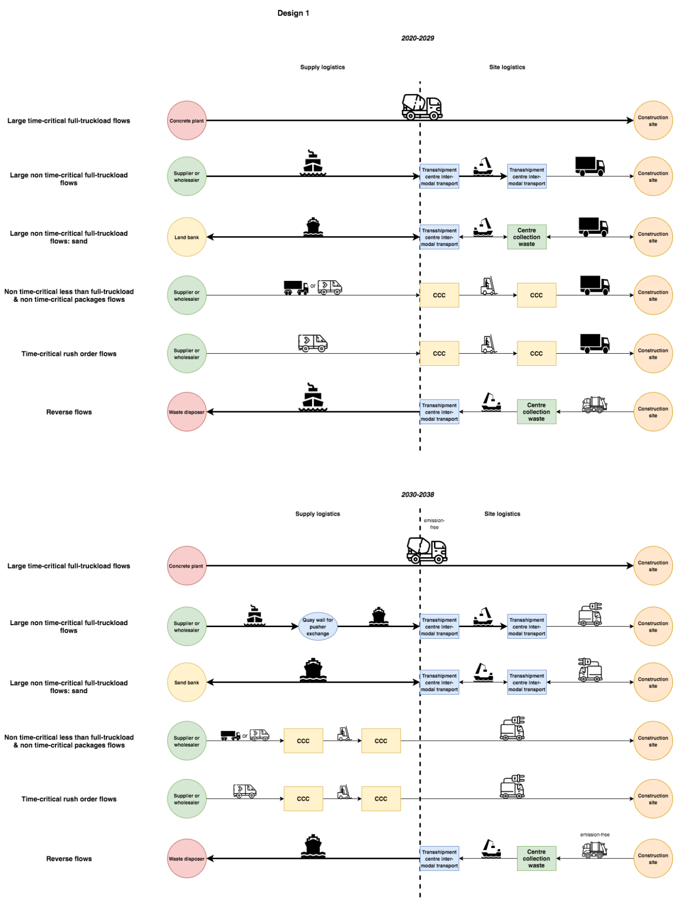

Fig. 2: Construction logistics structure design 1

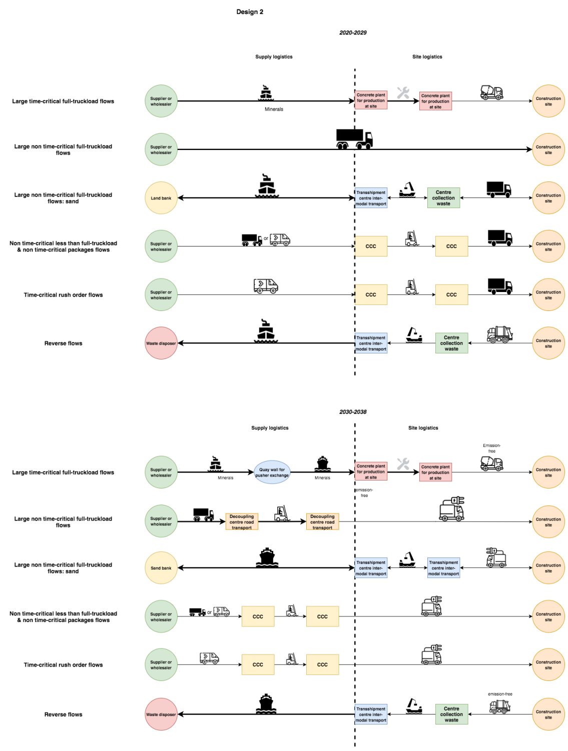

Fig. 3: Construction logistics structure design 2

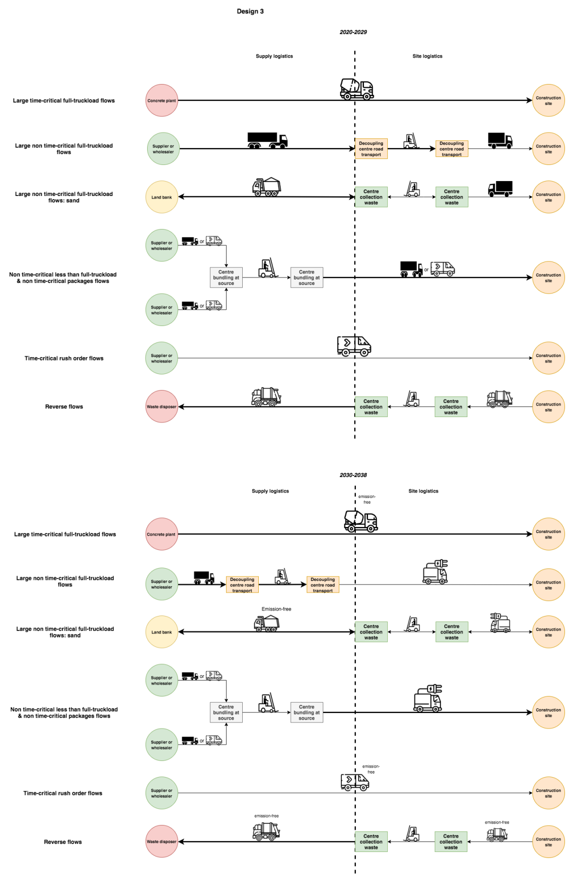

Fig. 4: Construction logistics structure design 3

VII. Calculation model & design verification

A calculation model in Microsoft Excel was developed to calculate the vehicle movements and the CO_2-, PM_x- and NO_x-emissions for each construction logistics structure. Logistics data of a reference construction project was used to develop this model. The new designs were tested on the requirements both qualitatively and quantitatively. The qualitative test was carried out by checking whether the requirement was present in the design of the new construction logistics structure or not. The quantitative test was performed with the calculation model. The outcomes of the calculation model showed significant reductions in emissions for all three new designs relative to the conventional logistics structure. The results are shown in table II. Per emission category, it is indicated which design scores best (green), moderate (orange) or worst (red).

TABLE II: Percentage reduction CO_2-, PM_x- and NO_x-emissions new designs with respect to conventional construction logistics structure

	Design 1	Design 2	Design 3
Reduction CO_2-emissions [%]	32,07	16,10	34,89
Reduction PM_x-emissions [%]	20,61	52,99	40,11
Reduction NO_x-emissions [%]	27,80	25,55	50,92

In addition, the results of the designs displayed a high decrease of required transport towards IJburg II, but an equal amount or even small increase of transport movements on IJburg II. This can be seen in table III.

TABLE III: Overview of average vehicle & barge movements per week

	Conventional structure	Design 1	Design 2	Design 3
Average vehicle movements to IJburg II 2020-2029 [vehicles/week]	204	123	77	151
Average vehicle movements to IJburg II 2030-2038 [vehicles/week]	191	87	99	137
Average vehicle movements to IJburg II 2020-2038 [vehicles/week]	197	105	88	144
Average vehicle movements on IJburg II 2020-2029 [vehicles/week]	204	217	184	193
Average vehicle movements on IJburg II 2030-2038 [vehicles/week]	191	225	225	200
Average vehicle movements on IJburg II 2020-2038 [vehicles/week]	197	221	204	197
Average barge movements to IJburg II 2020-2029 [barges/week]	0	5	8	0
Average barge movements to IJburg II 2030-2038 [barges/week]	0	6	7	0
Average barge movements to IJburg II 2020-2038 [barges/week]	0	6	8	0

The three designs were tested on the requirements in the design verification. The need to haves were tested binary, while scores were used for the nice to haves. The design verification showed that two of the three designs, design 1 and 3, fulfill the need to haves (minimal requirements). Out of the two designs that comply to the need to haves, design 1 scores best on the nice to haves due to the inclusion of waterborne transport and a higher decrease of congestion by construction logistics movements.

VIII. Evaluation Construction Logistics Structures IJburg II

The stakeholder analysis stated that many stakeholders have a high interest and power in the construction logistics structure. The Municipality of Amsterdam is identified as the stakeholder with the highest power and interest because the Municipality is land owner and regulative power. In addition, the Municipality is responsible for a livable city which gives the Municipality a high interest in the construction logistics structure. Furthermore, two other influential stakeholders were identified: the project developers and stakeholders. What else was found, is that the Municipality of Amsterdam has a number of control options to influence the construction logistics structure. These are regulating, coordinating, facilitating and stimulating measures. The number of control options are highest in the preliminary phase of construction activities.

The feasible construction logistics structures, design 1 and 3, were evaluated on the stakeholders' perceptions. To identify the stakeholders of the logistics structure for IJburg II, a stakeholder analysis was performed. The perceptions of the following six stakeholder groups were evaluated: the Municipality of Amsterdam, contractors, project developers, road & waterborne freight transporters and new inhabitants of IJburg II. The evaluation showed that the six evaluated stakeholder groups see some downsides in the feasible construction logistics structures related to their own interests. So, not every stakeholder group is equally positive about changing the construction logistics structure. Stakeholders have various problems with the impact of the structure on their own interests. Therefore, in order to realize a new structure, the Municipality of Amsterdam should specifically engage stakeholders who feel impacted by the changing structure. In addition, the first steps towards an implementation plan for construction logistics structure design 1 were made. For the above mentioned stakeholders groups, it was identified in which issue of the structure they have an interest.

IX. Conclusions, reflection & recommendations for further research

The design objective of this study was achieved as two of the three conceptual construction logistics structures meet the new ambitions of the Municipality of Amsterdam related to construction logistics and construction activities.

The results of the calculation model showed that all the three new construction logistics structures establish a high reduction in CO_2-, PM_x- and NO_x-emissions. In addition, all the designs significantly reduce the number of vehicle movements towards IJburg II. However, the vehicle movements on IJburg II (last-mile deliveries) remain unchanged or even slightly increase in the new designs what can be explained by the deployment of light electric vehicles. Since IJburg II is not a one of a kind project in the Netherlands, the outcomes of this study can be generalized. This implies that other similar urban development projects can achieve significant reductions of CO_2-, PM_x- and NO_x-emissions by implementing new logistics structures. The same applies for the conclusions about vehicle movements towards construction sites and about the last-mile deliveries.

Based on the the evaluation of the design on the stakeholders' perceptions, the first steps towards an implementation plan for design 1 were made, as this design scored best on the nice to haves. The implementation plan states that the Municipality of Amsterdam should specifically involve stakeholders for realizing the logistics structure. This targeted approach is effective because stakeholders only have issues with changes in the logistics structure that impact their own interests. However, before a new structure can be implemented, the design should be evaluated on more criteria such as costs, efficiency, safety and required land for logistics centres. This is necessary because the research focused mainly on the (environmental) benefits of the structure and not on the costs. Furthermore, it would be useful to do more research to construction logistics structures for infrastructural development in urban development projects, as this was not included. This extra research will increase the chances of a successful implementation. Two recommended directions for further research are thus to study the costs of new logistics structures and to design structures for infrastructural development.

Due to time limitations, the study only developed and examined three construction logistics structures. However, many more structures for IJburg II can be made by combining designs of subsystems which were drafted in this research. The paper states that two designed structures comply to the new requirements but this does not automatically mean that these are the best and only solutions. Therefore, the discussed approach in this paper can be used as a tool for the Municipality of Amsterdam and other municipalities, who encounter the same problems in similar construction projects, to develop new construction logistics structures. A recommendation for the Municipality of Amsterdam is thus to design and examine more logistics structures. In addition, it would be good for the Municipality to review all ambitions and strategies related to construction logistics and construction again to evaluate whether they actually match the goals of the Municipality.

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B Consultation group

The employees of the Municipality of Amsterdam that took part in the consultation group are listed in table 20. In addition, a list of topics discussed in the consultation group is presented.

Table 20: Participants consultation group

Name participant	Function
	Projectleider Openbare Ruimte
	Projectleider Kunstwerken
	Adviseur Duurzame Gebiedsontwikkeling
	Adviseur Programma Logistiek
	Projectleider Grond & Ontwikkeling

List of discussed topics

- Definition of emission-free transport.
- Requirements circular materials.
- Waterborne transport for construction materials.
- Locations for construction logistics centres.
- Ambitions and strategies Municipality of Amsterdam regarding construction logistics for IJburg II: vehicle standards, last-mile deliveries, transshipment equipment.
- The likelihood of continuing with planned ambitions and strategies.
- The willingness of the Municipality of Amsterdam to regulate, coordinate, facilitate and stimulate new construction logistics structures.

C Specifications construction Strandeiland

The sequence land reclamation and building heights of Strandeiland are illustrated in figures 23 and 24.

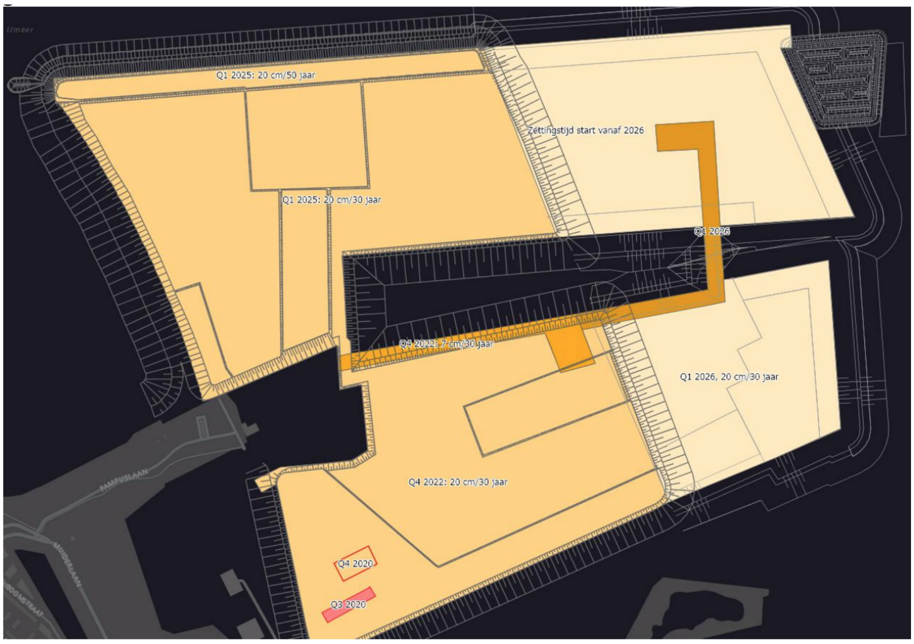

Figure 23: Sequence land reclamation Strandeiland (Gemeente Amsterdam, 2020c)

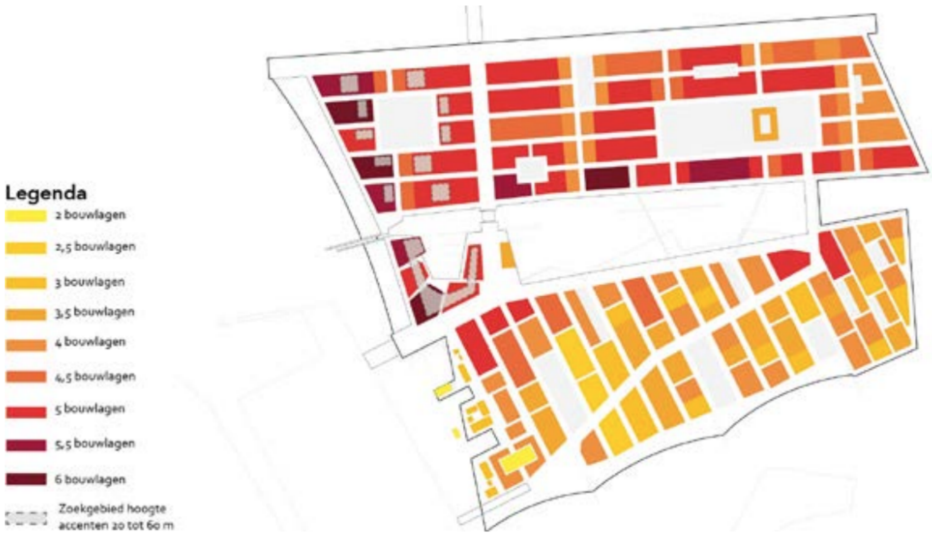

Figure 24: Building heights Strandeiland (Gemeente Amsterdam, 2019b)

D Symbols designs

In this appendix, the icons are shown that are used in the schematic representations of the subsystem designs. The various icons are displayed in the figures 25 and 26.

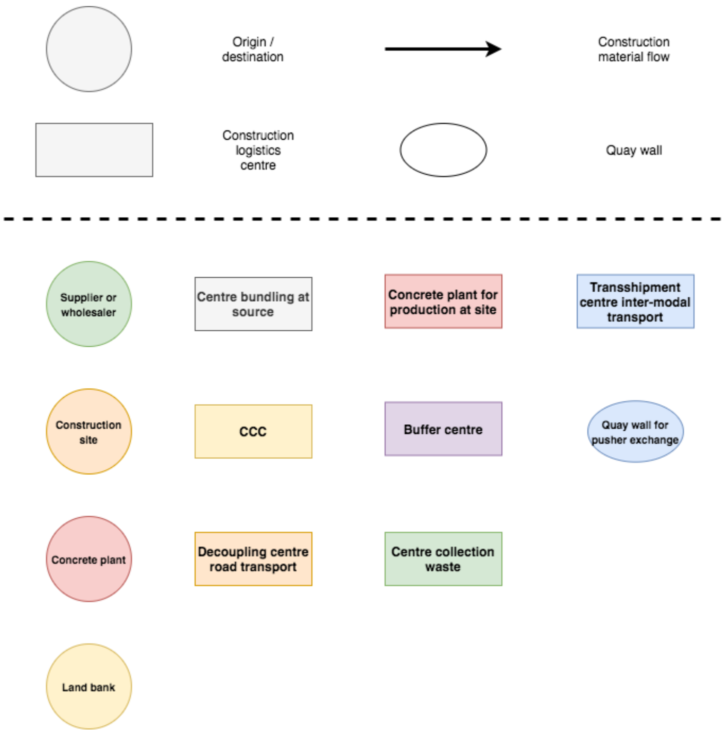

Figure 25: Symbols origins, destinations and construction logistics centres

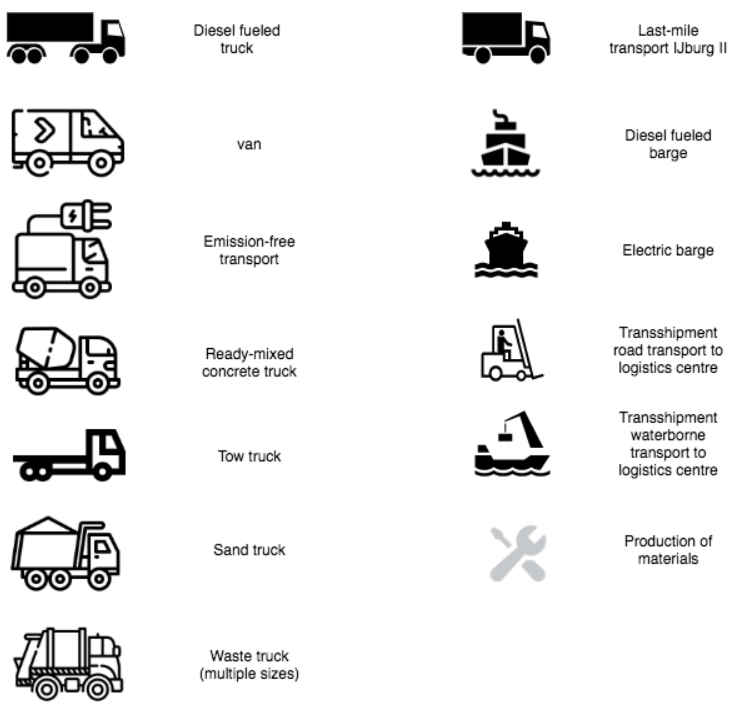

Figure 26: Symbols transport vehicles

E Construction logistics solutions residential and non-residential development

Studies of De Bes et al. (2018), Quak et al. (2011) and Merrienboer (2013) investigated a set of construction logistics solutions for residential and non-residential construction projects. Each of the solutions aims to reduce the number of vehicle movements between the supplier and the construction site. Consequently, this leads to a smaller impact of construction logistics on the urban environment. The measures can also be used in combination with each other in a construction logistics structure. The most relevant construction logistics solutions found in these researches are listed and explained below (De Bes et al., 2018) (Quak et al., 2011) Merrienboer (2013):

- *Bundling at the source.* This can be done by choosing suppliers close to each other and in the neighborhood of the construction site. In this way, the suppliers can organize and coordinate transports to the construction site in consultation with one another. A logistics centre can be used to bundle these flows.
- *Decoupling point.* A decoupling point is a facility where material flows can be decoupled to smaller streams and subsequently transported to the construction site.
- *Consolidation and the assembly of work packages.* By making use of a construction logistics centre, the number of movements towards the construction site can be minimized. The logistics centre can also be used as a place where work packages can be prepared. These packages can then be sent just-in-time (JIT) to the construction site.
- *Industrialisation of the construction process.* Less transport of construction materials is needed when the construction process is industrialized. Modules for construction can be pre-fabricated in factories and transported to the building site. In the future, the application of 3D-printing is also one of the possibilities.
- *Buffer area and traffic management.* A buffer or waiting area for trucks delivering JIT-deliveries can be used to prevent trucks entering the construction site when there is no space for loading or unloading. Traffic management can be deployed for the use of preferred routes.
- *Planning and communication.* A planning system will improve the steps in the construction logistics process. A ticket system can provide coordination between transport deliveries and the construction site.
- *Modal shift and shift in transport types.* There is a possibility for construction companies to shift in vehicle types. This implies particularly the shift from diesel or gasoline powered vehicles to electric vans or trucks. A modal shift can be achieved when switching from road to rail or waterborne transport. A logistics centre for transshipment is needed for this solution.
- *Efficient on-site logistics.* The deployment of so called runners on the construction site who are responsible for transporting construction materials to the right place on site. In this way, construction companies do not have to focus on the transportation of materials.
- *Smart reverse flows.* The proper management of reverse and waste flows via a central collection point or temporary storage of construction waste. Waste can be disposed via a CCC combined with the use of the empty capacity of delivery vehicles.

F Transport modes

This appendix elaborates more in depth upon the current state of road and waterborne transport for construction materials.

F.1 Road transport

Transport of construction materials by road can be performed by different vehicles. The best vehicle type depends on the type of cargo. A number of vehicle types used for road transport are: 1. kipper for the transportation of sand; 2. concrete truck 3. heavy truck; 4. light truck; 5. van; and 6. waste truck. The fuel technology of trucks and vans is quickly evolving over time. However, most of the trucks and vans are still powered by diesel engines. Ultimately, the Municipality of Amsterdam has the ambition to be emission-free which means that the diesel powered vehicles should be replaced. There are two important technologies that, in the long run, can ensure emission-free road transport: electric and hydrogen-powered trucks (Jorritsma, 2018). However, there is still a long way to go before these two technologies can replace diesel completely. A good alternative for this transition period can be Liquefied Natural Gas (LNG) or Compressed Natural Gas (CNG). All these new fuel technologies are discussed below.

Electric vans and trucks

Electric trucks are powered by an electric engine. This electric engine gets his fuel by electric cells in a battery. Electric driving is growing in the light truck and vans segment. Currently, these types of vehicles are mainly used for urban or urban regional transport for so called last-mile deliveries. Truck manufacturers such as Volvo, MAN and DAF are highly committed to developing electric light trucks and the first mass-produced electric light trucks are now a fact (Dijkhuizen, 2020). The average range of the light electric trucks is about 300 kilometres (Jorritsma, 2018). Bearing in mind that more than 80% of the road freight transport journeys are of distances below the 80 kilometers (Kok et al., 2017), there is a huge potential to deploy light electric trucks for this purpose. However, the first electric trucks cannot be used for transporting heavy construction materials. These light electric trucks are currently deployed for waste disposal and urban logistics because they have a gross weight of 27.000 kg (Seijlhouwer, 2019).

Electric vans are already driving around the inner cities in larger numbers. A lot of car manufacturing companies now introduce their own electric van such as Ford and Renault (Dijkhuizen, 2020). These vans are not suited for transporting heavy construction materials. These days, the vans are used for transport of personnel and for deliveries of small packages. To date, the percentage of freight delivered by electric vans is still low. Numbers of the CBS from 2018 show that only 0.1% (40.000 kg) of the total transported freight in the Netherlands is delivered by an electric van (Dijkhuizen, 2020). Furthermore, these numbers showed that 98% of the vans were diesel powered. Therefore, major steps will have to be taken to achieve zero-emission deliveries in the near future.

Electric medium and heavy sized trucks with a long range are not available yet, these are still being developed. Some concepts have been introduced but it seems that electric trucks in this segment will take some time before they are operational (Dijkhuizen, 2020). The concept trucks in this category presented in 2019 had a maximum gross weight of 44.000 kg (Seijlhouwer, 2019). However, For short distances and last-mile deliveries, small electric tow trucks are available that can transport heavy construction materials a few kilometres. This can be a solution for last-mile deliveries on IJburg II.

A large-scale charging infrastructure is needed to successfully and feasibly implement electric trucks. At the moment, there is a lack of charging infrastructure. This limits the distance of electric vehicles. Other possible barriers for implementation are the higher prices of electric freight vehicles (Kok et al., 2017). This makes electric vehicles not feasible for freight carriers to operate because depending on the specifications of the electric truck, the purchase price is twice as high compared to diesel powered trucks (Kok et al., 2017). That is why, freight carriers often prefer the conventional truck. The choice can be made more attractive when the costs of CO2-emissions are internalized. Moreover, the batteries are not only expensive but also heavy which means a lower payload (Kok et al., 2017). Furthermore, at the moment there is little data available about the performance and reliability of electric trucks which makes the implementation more difficult. However, currently the biggest problem for the implementation of electric trucks in the construction logistics structure is the ability to carry heavy construction materials over longer distances.

Electric trucks provide the opportunity for sustainable transport in the category of lighter and smaller construction materials at shorter distances. A pilot in Rotterdam making use of electric light truck for the transportation of scaffolding materials is a success (Jorritsma, 2019). The electric truck can carry less materials than the conventional truck which means that the deliveries are smaller. However, this is not seen as a disadvantage because there is less storage space needed on the construction site. In addition, electric trucks are now being tested for the disposal of waste materials, up to now with positive results (Jorritsma, 2018).

Hydrogen-powered trucks

The hydrogen-powered trucks are also powered by electric engines. However, the electricity is in this case delivered by a fuel cell in which hydrogen reacts with oxygen to produce electricity. Just like the electric heavy trucks are the hydrogen trucks still in development. The American manufacturer Nikola and the Dutch manufacture VDL are examples of companies that are working on this kind of trucks. VDL is currently building a 27.000 kg gross weight truck on hydrogen designed for logistics purposes (Jorritsma, 2018).

The availability of solid infrastructure to refuel hydrogen powered vehicles is a point of concern (Jorritsma, 2018). At the moment, there are only three locations where hydrogen can be refueled. Therefore, research is done to mobile hydrogen fuel stations. Disadvantage is that the production of hydrogen is highly energy consuming process. The electricity to produce hydrogen via electrolysis has to be generated green before driving trucks on hydrogen gas is a real sustainable alternative.

The advantage of hydrogen-powered trucks over electric trucks is that these do not need batteries. The durability and impact on the environment of an electric battery are unknown (Jorritsma, 2018). These batteries are also very expensive which makes electric trucks in the future compared to hydrogen-powered trucks less attractive.

Alternative powered trucks

CNG and LNG

In the short term, the transformation to full electric or emission-free road transport for construction materials does not seem likely. In the mean time, there must be looked at a more feasible alternative for replacing diesel powered vans and trucks for delivery of construction materials. Liquefied Natural Gas (LNG) and Compressed Natural Gas (CNG) are often named as the most promising alternatives to replace diesel in the transition period to full electric trucks, especially for long distances (Jorritsma, 2018) (Mensch, 2016). Most of the truck manufacturers has a LNG and CNG model in all the truck categories (light, medium and heavy). Currently, 500 LNG trucks drive around the Netherlands for freight transport purposes (Dijkhuizen, 2020). For CNG this number is even higher. Those trucks can refuel at 27 LNG fuel stations and 145 CNG stations around the Netherlands (Dijkhuizen, 2020). The network of LNG and CNG fuel stations is expanding quickly which is also necessary to make driving on LNG and CNG more attractive for freight carriers. CNG trucks are best suited for short distances and LNG trucks for regional or national transport. Both of the technologies have the advantage to be relatively quiet compared to a diesel engine (Mensch, 2016).

However, recent research of TNO suggests that the LNG alternative is not that more sustainable than a diesel EURO VI (the cleanest diesel truck) (Vermeulen et al., 2017). This study states that a LNG truck emits on average 3-6% and on highways 10% less greenhouse gases than the EURO VI diesel trucks (Vermeulen et al., 2017). In addition, the emission of particulate matters and Nitrogen oxide were equal to the emissions of a EURO VI diesel truck. This implies that LNG is not that more sustainable than a clean diesel truck. For CNG, there is not such an extensive comparative research available. Another point of attention for LNG and CNG is the fact that it still is a fossil fuel. A green solution for this is the production of bio-LNG and bio-CNG out of manure and organic waste.

Hybrid trucks

A combination of fuel technologies is also a possibility for the propulsion of trucks. A hybrid truck is propelled by both an electric motor and an internal diesel combustion engine. This enables the truck to drive electrically for short distances which leads to a decrease in the fuel consumption (Mensch, 2016). However, when deployed for long distances, the fuel consumption can even be larger than an conventional truck due to the weight of the batteries. The hybrid truck is therefore mainly beneficial for short distances and can achieve a CO2 reduction of 10-25% (Mensch, 2016).

Dual fuel trucks

CNG and LNG can also be combined with a conventional diesel combustion engine. These are called the CNG or LNG dual fuel trucks. Practically, the dual fuel engine is a diesel engine but with a more beneficial fuel consumption due to possibility to use CNG or LNG (Mensch, 2016). If there is no CNG or LNG available, the truck can drive seamlessly on just diesel. The expected reduction of CO2-emissions with this kind of engines is 10% with an admixture percentage of 50% CNG or LNG. The CNG or LNG dual fuel trucks are preferably deployed for regional or national transport. Due to the presence of the diesel engine, there is no noise advantage above the conventional diesel engines (Mensch, 2016).

F.2 Vessels

Construction materials are mainly transported in pushed barges or ponton barges (van Rijn et al., 2020). These types of ships are attractive because of the high load capacity and the possibility of combining the barges which leads to economies of scale (Macharis et al., 2011). In the Netherlands, barges are available in different sizes and are propelled by so called pushers (de Leeuw van Weenen et al., 2018). The conventional pusher is equipped with a heavy diesel engine which is not sustainable. The last few years, hybrid ships are developed with a combination of diesel and electric engines. However, at the moment, research is also done to zero-emission transport by water. The two most promising techniques are elaborated below.

The transition to zero-emission vessels is a pillar in the climate agreement of the Dutch government. In 2030, the goal is to have 150 zero-emission ships sailing on Dutch inland waterways. The first electric vessels are now sailing in the canals of Amsterdam for construction logistics and waste disposal purposes. However, these ships are not able to transport large volumes over longer distances. The two alternatives for replacing diesel engines are, as with trucks, either electric batteries or fuel cells in combination with hydrogen (van Rijn et al., 2020). These variants can be carried out differently. Electric batteries can make use of: 1) battery packages that can be charged at locations along waterways, 2) replaceable batteries that can be switched or charged 3) redux flow batteries. Hydrogen powered vessels can make use of: 1) compressed hydrogen, 2) cooled hydrogen or 3) a chemical fluid to which hydrogen is bonded (van Rijn et al., 2020).

The implementation of these technologies need to be investigated in more depth. The feasibility of these techniques depends, among others, on the characteristics of the transported materials, safety issues and availability of the charging infrastructure.

G Calculation model

This appendix presents the calculations that were conducted to determine the vehicle movements, CO_2-, PM_x- and NO_x-emissions for each construction logistics structure. The calculations are divided in three parts: calculations to determine the vehicle movements of the conventional construction logistics structure, calculations to convert the vehicle movements of the conventional logistics structure to vehicle movements of the new construction logistics structures and calculations to determine the CO_2-, PM_x- and NO_x-emissions.

G.1 Vehicle movements conventional construction logistics structure

The vehicle movements for the conventional construction logistics structure were calculated for two construction methods: the hybrid and the circular method. Table 21 displays the calculations for the hybrid and circular construction method. The results of these calculations were used to calculate the vehicle movements per time period with which ultimately the total vehicle movements for 2020-2029 and 2030-2038 were determined. These calculations are illustrated in tables 22 and 23.

Table 21: Calculations for vehicle movements hybrid and circular method

Preparation construction site
Kipper [-] = *Excavated soil residential and non-residential structures[m³]/(max. capacity kipper [m³])*(100/ load factor[%])*
Substructure & shell construction
Van [-] = *(# houses [-] / # houses ref. project [-])*factor vehicles ref. project [-]*(1+GFA facilities [m²]/GFA residences [m²])*(100/ load factor[%])*
Heavy truck [-] = *(# houses [-] / # houses ref. project [-])*factor vehicles ref. project [-]*(1+GFA facilities [m²]/GFA residences [m²])*(100/ load factor[%])*
Kipper [-] = *(((100/sand in building [%])*(materialization building [kg/m²]*total GFA [m²])/volumetric mass density [kg/m3]) /(max. capacity kipper [m³]* (load factor[%]/100))*
Light truck [-] = *(# houses [-] / # houses ref. project [-])*factor vehicles ref. project [-]*(1+GFA facilities [m²]/GFA residences [m²])*(100/ load factor[%])*
Concrete truck for piles [-] = *(volume pile [m³] *# houses [-]*(1+GFA facilities [m²]/GFA residences [m²]))/(max. capacity concrete truck [m³])*(load factor[%]/100)*
Concrete truck [-] = *(factor vehicles ref. project [-] *((100/concrete in building [%])*(materialization building [kg/m²]*total GFA [m²])/volumetric mass density [kg/m3]) /(max. capacity concrete truck [m³]*(load factor[%]/100)) – Concrete truck for piles*
Waste truck [-] = *(0,5*((0,1*materialization building [kg/m²]*total GFA [m²])/volumetric mass density [kg/m3]) /(max. capacity waste truck [m³]*(load factor[%]/100))*
Final construction
Van [-] = *(# houses [-] / # houses ref. project [-])*factor vehicles ref. project [-]*(1+GFA facilities [m²]/GFA residences [m²])*(100/ load factor[%])*
Heavy truck [-] = *(# houses [-] / # houses ref. project [-])*factor vehicles ref. project [-]*(1+GFA facilities [m²]/GFA residences [m²])*(100/ load factor[%])*
Light truck [-] =*(# houses [-] / # houses ref. project [-])*factor vehicles ref. project [-]*(1+GFA facilities [m²]/GFA residences [m²])*(100/ load factor[%])*
Concrete truck [-] = *(factor vehicles ref. project [-] *((100/concrete in building [%])*(materialization building [kg/m²]*total GFA [m²])/volumetric mass density [kg/m3]) /(max. capacity concrete truck [m³]*(load factor[%]/100)) – Concrete truck for piles*
Waste truck [-] = *(0,5*((0,1*materialization building [kg/m²]*total GFA [m²])/volumetric mass density [kg/m3]) /(max. capacity waste truck [m³]*(load factor[%]/100))*

Table 22: Calculations for vehicle movements per time period

Vehicle movements 2020-2022 per week
Vehicle movements [-] *= total # vehicle movements Centrumeiland [-] / (total Construction time [years]/52 [weeks])*
Vehicle movements 2023-2025 per week
Vehicle movements [-] *= (total # vehicle movements Centrumeiland [-] / (total Construction time [years]/52 [weeks])) + (Total # vehicle movements Strandeiland hybrid method [-] / (total Construction time [years]/52 [weeks]))*
Vehicle movements 2026-2029 per week
Vehicle movements [-] *= (total # vehicle movements Strandeiland hybrid method [-] / (total Construction time [years]/52 [weeks]))*
Vehicle movements 2030-2038 per week
Vehicle movements [-] *= (total # vehicle movements Strandeiland circular method [-] / (total Construction time [years]/52 [weeks]))*

Table 23: Calculations for vehicle movements 2020-2029 & 2030-2038

Total vehicle movements 2020-2029
Vehicle movements [-] *= (vehicle movements per week 2020-2022 * construction time [years] + vehicle movements per week 2023-2025 * construction time [years] + vehicle movements per week 2026-2029 * construction time [years])* 52 [weeks]*
Total vehicle movements 2030-2038
Vehicle movements [-] *= (vehicle movements per week 2030-2038 * construction time [years])*52 [weeks]*

G.2 Vehicle movements new construction logistics structure designs

The calculations to adjust the conventional construction logistics structure to the new structure designs are displayed in table 24.

Table 24: Calculations for implementation construction logistics centres

1. Centre for bundling at the source
Final construction
Van, Heavy truck, light truck [-] *= # vehicle movements conventional structure [-] * (100/load factor [%])*
Transshipment [-] *= # New vehicle movements van [-] + # new vehicle movements heavy truck [-] + # new vehicle movements light truck [-]*
2. Construction consolidation centre
Final construction
Transshipment [-] *= # New vehicle movements van [-] + # new vehicle movements heavy truck[-] + # new vehicle movements light truck [-]*
Last-mile transport *[-] = # vehicle movements conventional structure van [-] * (100/load factor [%]) + # vehicle movements conventional structure heavy truck [-] * (100/load factor [%]) + # vehicle movements conventional structure light [-] * (100/load factor [%])*
3. Decoupling centre for road transport
Substructure & shell construction
Transshipment [-] *= # vehicle movements conventional structure heavy truck [-]*
Last-mile transport [-] *= 2 *# vehicle movements conventional structure heavy truck [-]*
4. Centre for production at the site
Substructure & shell construction
Concrete truck [-] *= 0*
Concrete truck for piles [-] *= 0*
Push barge [-] *= ((# vehicle movements conventional structure concrete truck [-] + # vehicle movements conventional structure concrete truck for piles [-])*max. capacity concrete truck [m^3] * volumetric mass density concrete mortar [kg/m3])/ max. capacity push barge [kg]*
Transshipment [-] *= # New vehicle movements push barge [-]*
Last-mile transport [-] *= # vehicle movements conventional structure concrete truck [-] + # vehicle movements conventional structure concrete truck for piles [-]*
5. Buffer centre
No adjustments vehicle movements

6. Centre for production at the site
Preparation construction site
Kipper [-] *= # vehicle movements conventional structure kipper [-] / (100/load factor [%])*
Transshipment [-] *= # New vehicle movements kipper [-]*
Last-mile transport [-] *= # vehicle movements conventional structure kipper [-]*
Substructure & shell construction
Kipper [-] *= # vehicle movements conventional structure kipper [-] / (100/load factor [%])*
Transshipment [-] *= # New vehicle movements kipper [-]*
Last-mile transport [-] *= # vehicle movements conventional structure kipper [-]*
Waste truck [-] *= # vehicle movements conventional structure waste truck [-] / (100/load factor [%])*
Transshipment [-] *= # New vehicle movements waste truck [-]*
Last-mile transport [-] *= # vehicle movements conventional structure waste truck [-]*
Final construction
Waste truck [-] *= # vehicle movements conventional structure waste truck [-] / (100/load factor [%])*
Transshipment [-] *= # New vehicle movements waste truck [-]*
Last-mile transport [-] *= # vehicle movements conventional structure waste truck [-]*

7. Transshipment centre for inter-modal transport
Preparation construction site
Kipper [-] *= 0*
Push barge [-] *= (# vehicle movements conventional structure kipper [-]*max. capacity kipper [m^3] * volumetric mass density sand [kg/m3])/ max. capacity push barge [kg]*
Transshipment [-] *= # New vehicle movements push barge [-]*
Last-mile transport [-] *= # vehicle movements conventional structure kipper [-]*
Substructure & shell construction
Heavy truck [-] *= 0*
Kipper [-] *= 0*
Waste truck [-] *= 0*
Push barge [-] *= ((# vehicle movements conventional structure kipper [-]*max. capacity kipper [m^3] * volumetric mass density sand [kg/m3])/ max. capacity push barge [kg])+(# vehicle movements conventional structure heavy truck/ conversion factor heavy trucks in barge)*
Transshipment *= # New vehicle movements push barge [-] + Construction time [years] * 52 [weeks]*
Last-mile transport [-] *= # vehicle movements conventional structure heavy truck [-] + # vehicle movements conventional structure kipper [-] + # vehicle movements conventional structure waste truck [-]*
Final construction
Push barge [-] *= Construction time [years] * 52 [weeks]*
Transshipment [-] *= # New vehicle movements push barge [-]*
Last-mile transport [-] *= # vehicle movements conventional structure waste truck [-]*

G.3 CO_2-, PM_x- and NO_x-emissions construction logistics movements

The calculations that were made to determine the CO_2-, PM_x- and NO_x-emissions per construction logistics structure due to vehicle movements are illustrated in table 25.

Table 25: Calculations for emissions vehicle movements

Emissions
CO_2-emissions [kg/ton] *= # vehicle movements [-] *roundtrip distance [km]* emission factor CO_2 [g/ton]/ 1000*
PM_x-emissions [kg/ton] *= # vehicle movements [-] *roundtrip distance [km]* (emission factor PM_{engine} + emission factor PM_{wear}) [g/ton]/ 1000*
NO_x-emissions [kg/ton] *= # vehicle movements [-] *roundtrip distance [km]* emission factor NO_x [g/ton]/ 1000*
Reduction CO_2-emissions [%] *= ((CO_2-emissions new design [kg/ton] - CO_2-emissions conventional structure [kg/ton])/ - CO_2-emissions conventional structure [kg/ton])*100 [-]*
Reduction Mx-emissions [%] *= ((PMx-emissions new design [kg/ton] - Mx-emissions conventional structure [kg/ton])/ - Mx-emissions conventional structure [kg/ton])*100 [-]*
Reduction NOx-emissions [%] *= ((NOx-emissions new design [kg/ton] - NOx-emissions conventional structure [kg/ton])/ - NOx-emissions conventional structure [kg/ton])*100 [-]*

H Assumptions and case-specific input values calculation model

This Appendix presents the key assumptions and case-specific values used in the calculation model. The assumptions are stated in table 26 and the case-specific values in table 27.

Table 26: Assumptions calculation model

Assumption	Description	Reference
1.	From 2020 until 2029 construction activities are performed with the hybrid method (prefab elements and in-situ ready-mixed concrete)	Gemeente Amsterdam (2016), Gemeente Amsterdam (2019b)
2.	From 2030 construction activities are performed with circular materials	Gemeente Amsterdam (2019b)
3.	From 2020 until 2038 the foundation will be constructed with in-situ cast piles	Kuiper (2020)
4.	One push barge replaces 15 heavy trucks	demolenaar.nl/2010/12/01/eerste-serie-duwbakken-de-heus-volledig-operationeel/
5.	10 piles are required for the foundation of one house on IJburg II	www.offerteadviseur.nl/categorie/bouw/verbouwing/kosten-heiwerken/
6.	One pile is 25 meters long	eh-architects.nl/zelfbouwblok-59-ijburg-amsterdam-fundering-gereed/
7.	500 ton push barges are used for the transportation of construction materials	demolenaar.nl/2010/12/01/eerste-serie-duwbakken-de-heus-volledig-operationeel/

Table 27: Case-specific values

Description	Value	Unit	Reference
Load factor			
Preparation construction site	70	%	De Bes et al (2018)
Substructure & shell construction	70	%	De Bes et al (2018)
Final construction	30	%	Rinsma et al. (2015)
# Houses			
Reference project	60	Houses	Rinsma et al. (2015)
Centrumeiland	1500	Houses	Gemeente Amsterdam (2016)
Strandeiland	8000	Houses	Gemeente Amsterdam (2019b)
Excavated soil			
Centrumeiland	36000	m^3	Post and Monen (2019)
Strandeiland	262500	m^3	Post and Monen (2019)
Gross floor area			
Centrumeiland residences	195654	m^2	Gemeente Amsterdam (2016)
Centrumeiland facilities	10298	m^2	Gemeente Amsterdam (2016)
Centrumeiland total	205952	m^2	Gemeente Amsterdam (2016)
Strandeiland residences	880000	m^2	Gemeente Amsterdam (2019b)
Strandeiland facilities	120000	m^2	Gemeente Amsterdam (2019b)
Strandeiland total	1000000	m^2	Gemeente Amsterdam (2019b)
Materialization building			
Average house	1600	kg/m^2	Arnoldussen et al. (2020)
Material in building			
Sand	2	%	Arnoldussen et al. (2020)
Concrete	80	%	Arnoldussen et al. (2020)

Description	Value	Unit	Reference
Vehicle capacity			
Kipper	20	m^3	Rinsma et al. (2015)
Concrete truck	12	m^3	Rinsma et al. (2015)
Waste truck (substructure & shell)	15	m^3	bouwafval.nl/afvalcontainer-15m3
Waste truck (final)	9	m^3	renewi.com/nl-nl/zakelijk/diensten/afvalinzameling/afzetcontainers/9m3-container
Push barge	500000	kg	www.demolenaar.nl/2010/12/01eerste-serie-duwbakken-de-heus-volledign-operationeel/
Round trip distance			
Suppliers water	250	km	Based on distance road transport. Higher because less dense network of waterways
Suppliers road	160	km	De Bes et al (2018)
Land bank	8	km	Gemeente Amsterdam (2019b)
Concrete plant	40	km	Desk research concrete plants in the surroundings of IJburg
Waste disposer	40	km	Desk research waste disposers in the surroundings of IJburg
Centre(s) outside the environmental zone	8	km	Desk research surroundings of IJburg
Loop construction traffic IJburg II	6	km	Gemeente Amsterdam (2019b)
Construction time			
Construction Centrumeiland	6	years	Gemeente Amsterdam (2016)
Construction Strandeiland	16	years	Gemeente Amsterdam (2019b)
Construction IJburg II	18	years	Gemeente Amsterdam (2016), Gemeente Amsterdam (2019b)

Description	Value	Unit	Reference
Piles			
Piles heavy truck	8	piles	ijbgroep.nl/projecten/scheepslading-ijsselmeerbeton-naar-westerschelde
Piles per house	10	piles	www.offerteadviseur.nl/categorie/bouw/verbouwing/kosten-heiwerken/
Volume concrete for piles per house	25,6	m^3	Assumption piles
Vehicles reference project			
Van (substructure & shell)	2	vehicles	Rinsma et al. (2015)
Van (final)	3	vehicles	Rinsma et al. (2015)
Heavy truck conventional (substructure & shell)	130	vehicles	Rinsma et al. (2015)
Heavy truck conventional-circular (final)	59	vehicles	Rinsma et al. (2015)
Heavy truck circular (substructure & shell)	209	vehicles	Rinsma et al. (2015)
Light truck (substructure & shell)	2	vehicles	Rinsma et al. (2015)
Light truck (final)	11	vehicles	Rinsma et al. (2015)
Concrete truck circular (substructure & shell)	0	vehicles	Assumption case study
Concrete truck conventional (substructure & shell)	0,45	factor	Assumption case study
Concrete truck conventional-circular (final)	0,075	factor	Assumption case study

Description	Value	Unit	Reference
Volumetric mass density			
Mortar	2100	kg/m^3	gwwmaterialen.blogspot.com/p/soortelijk-gewicht
Sand	1750	kg/m^3	gwwmaterialen.blogspot.com/p/soortelijk-gewicht
Concrete	2400	kg/m^3	gwwmaterialen.blogspot.com/p/soortelijk-gewicht
Waste	1800	kg/m^3	Average volumetric mass density construction materials

I Results Calculation Model

In this appendix, the results of the calculation model are presented.

I.1 Vehicle movements

The average vehicle movements per week for the conventional construction logistics structure and each new design per time period (2020-2029 and 2030-2038) are illustrated in figures 27, 28, 29 and 30. For each vehicle type it is indicated how many vehicle movements are required in which phase of construction. One vehicle movement represents one round trip.

2020-2029

Hybrid method with in-situ cast concrete piles

Total transport movements IJburg 2020-2029	Preparation construction site	Substructure construction & shell construction	Final construction	Total
Van	0	1	2	2
Heavy truck	0	33	35	68
Kipper	21	2	0	22
Light truck	0	0	7	7
Concrete truck for piles	0	30	0	30
Concrete truck	0	35	14	49
Waste truck	0	5	20	26
Total - transshipment	21	106	77	204

2030-2038

Circular structure with in-situ cast concrete piles

Total transport movements IJburg II 2030-2038	Preparation construction site	Substructure construction & shell construction	Final construction	Total
Van	0	1	2	2
Heavy truck	0	54	36	90
Kipper	23	2	0	24
Light truck	0	0	7	7
Concrete truck for piles	0	29	0	29
Concrete truck	0	0	13	13
Waste truck	0	5	20	25
Total - transshipment	23	91	77	191

Figure 27: Total vehicle movements per time period conventional structure

2020-2029

Hybrid method with in-situ cast concrete piles

Total transport movements IJburg 2020-2029	Preparation construction site	Substructure construction & shell construction	Final construction	Total
Van	0	1	2	2
Heavy truck	0	0	35	35
Kipper	0	0	0	0
Light truck	0	0	7	7
Concrete truck for piles	0	30	0	30
Concrete truck	0	35	14	49
Waste truck	0	0	0	0
500 ton push barge	1	2	1	5
Transhipment	1	3	44	49
Last-mile transport	21	73	44	138
Total - transshipment	22	141	102	265

2030-2038

Circular structure with in-situ cast concrete piles

Total transport movements IJburg II 2030-2038	Preparation construction site	Substructure construction & shell construction	Final construction	Total
Van	0	1	2	2
Heavy truck	0	0	36	36
Kipper	0	0	0	0
Light truck	0	0	7	7
Concrete truck for piles	0	29	0	29
Concrete truck	0	0	13	13
Waste truck	0	0	0	0
500 ton push barge	2	4	1	6
Transhipment	2	5	45	52
Last-mile transport	23	115	44	182
Total - transshipment	24	149	102	276

Figure 28: Total vehicle movements per time period design 1

2020-2029

Hybrid method with in-situ cast concrete piles

Total transport movements IJburg 2020-2029	Preparation construction site	Substructure construction & shell construction	Final construction	Total
Van	0	1	2	2
Heavy truck	0	33	35	68
Kipper	0	0	0	0
Light truck	0	0	7	7
Concrete truck for piles	0	0	0	0
Concrete truck	0	0	0	0
Waste truck	0	0	0	0
500 ton push barge	1	5	1	8
Transhipment	1	6	45	52
Last-mile transport	21	72	58	150
Total - transshipment	22	111	102	235

2030-2038

Circular structure with in-situ cast concrete piles

Total transport movements IJburg II 2030-2038	Preparation construction site	Substructure construction & shell construction	Final construction	Total
Van	0	1	2	2
Heavy truck	0	54	36	90
Kipper	0	0	0	0
Light truck	0	0	7	7
Concrete truck for piles	0	0	0	0
Concrete truck	0	0	0	0
Waste truck	0	0	0	0
500 ton push barge	2	4	1	7
Transhipment	2	60	46	107
Last-mile transport	23	145	57	224
Total - transshipment	24	204	103	331

Figure 29: Total vehicle movements per time period design 2

2020-2029

Hybrid method with in-situ cast concrete piles

Total transport movements IJburg 2020-2029	Preparation construction site	Substructure construction & shell construction	Final construction	Total
Van	0	1	1	1
Heavy truck	0	33	11	44
Kipper	15	1	0	16
Light truck	0	0	2	2
Concrete truck for piles	0	30	0	30
Concrete truck	0	35	14	49
Waste truck	0	4	6	10
Transhipment	15	38	19	71
Last-mile transport	21	73	20	114
Total - transshipment	35	177	53	265

2030-2038

Circular structure with in-situ cast concrete piles

Total transport movements IJburg II 2030-2038	Preparation construction site	Substructure construction & shell construction	Final construction	Total
Van	0	1	1	1
Heavy truck	0	54	11	65
Kipper	16	1	0	17
Light truck	0	0	2	2
Concrete truck for piles	0	29	0	29
Concrete truck	0	0	13	13
Waste truck	0	4	6	9
Transhipment	16	59	19	94
Last-mile transport	23	114	20	156
Total - transshipment	38	203	52	293

Figure 30: Total vehicle movements per time period design 3

I.2 Emissions

The total CO_2-, PM_x- and NO_x-emissions caused by vehicle movements for the conventional structure and the three newly designed structures are displayed in figure 31.

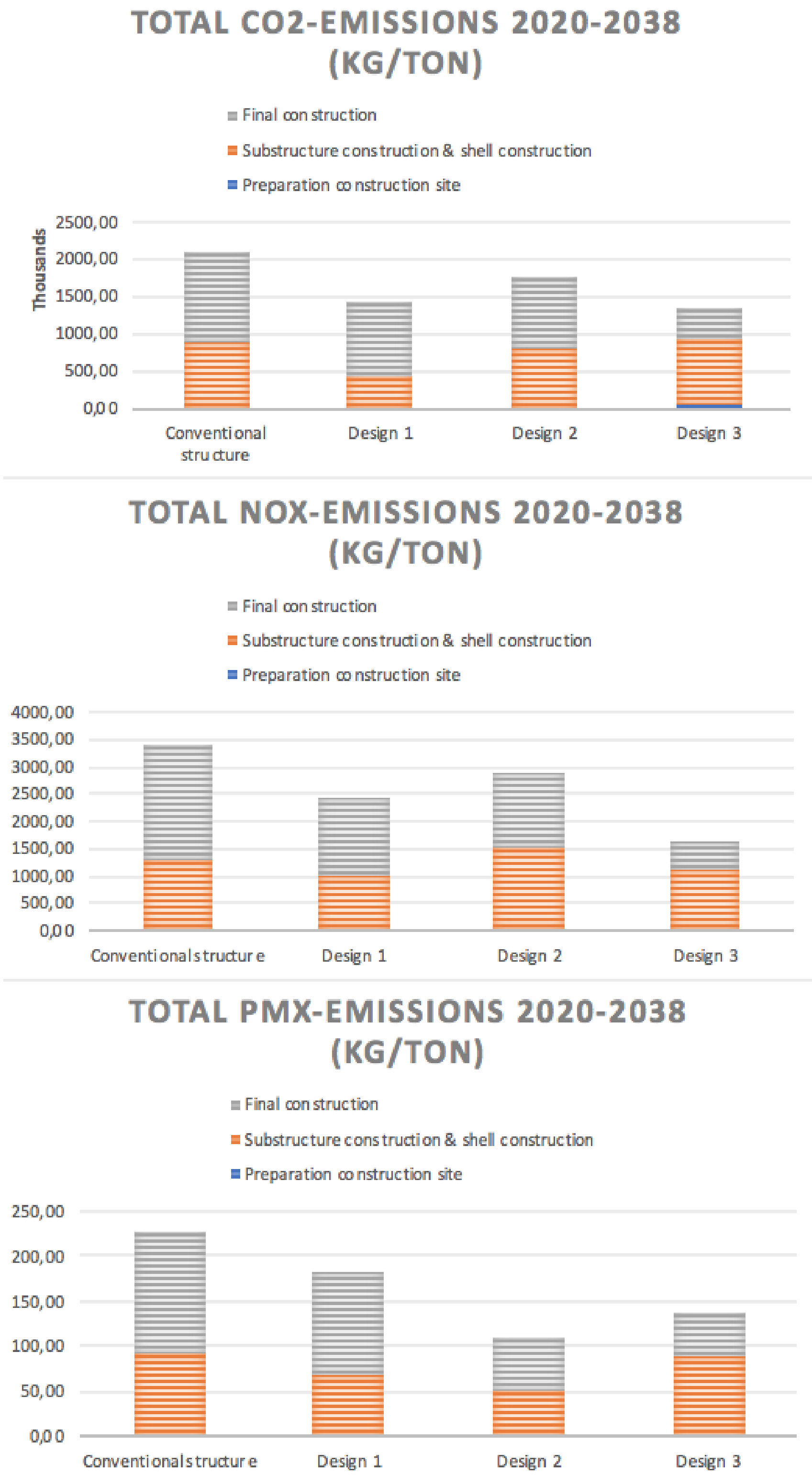

Figure 31: The total CO_2-, PM_x- and NO_x-emissions per structure