Combining Logistics Resources between Urban Construction Projects

A cross-sectional study for the city of Amsterdam

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Construction Management & Engineering - Digital Design & Asset Management

TU Delft

dutch process innovators

Cover Page: Construction site at Herengracht, Amsterdam
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A cross-sectional study for the city of Amsterdam

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Preface

During my master Construction Management & Engineering I had the opportunity to work for a construction management consultancy as a working student. I got to experience the management around the renovation of the south side of Amsterdam Central station where a new bicycle parking lot was being constructed underneath the canal. Based on my study, experience, and interests, I was asked to carry out several small assignments that could help make the work easier. Therefore, I had to work with several software programs: ThinkProject, Synchro and Autodesk. I noticed that, even though the company is moving towards digital management, there are still quite some complications to overcome to really use it to its advantage.
One of the first assignments that I did, was making a visualisation of the (expected) usage of resources. Since the project used a synchronised 4D BIM model of the construction, it was possible to visualize in which moment in time a specific element of the structure would be built. However, information on the object itself (e.g. concrete volume), was not connected with the model yet. My task was to connect the two sources of information, so it would be possible to estimate how many resources, for example construction workers, would be required to finish the task on time. Adding these up for all the tasks over time would then result in a graph where you could see the number of construction workers required in each day.
In the ideal world the connections would have been made within the BIM environment so there would be a single source of information. Since time was limited, I only had 4 working days to come with a result, the easy option was to extract the current information and start calculations within an Excel sheet. Within 4 days I had a working model that clearly showed in which weeks a resource will have a peak (according to the schedule). However, information is changing constantly, and every two weeks there would be a schedule update, the information had to be recalculated by changing the input values (project schedule). A side effect that would happen is that the naming of a certain task had been changed, and that information had to be reconnected manually to make the right calculations.
This made me wonder, since all the information is there, shouldn't we be able to connect everything from the start, so that simple changes, like illness of construction workers, shortage of construction material or machinery, would automatically have an influence on the expected finish date of a certain task if no counteractions are undertaken.
When I pitched the idea of digitally managing resources to Ruben Vrijhoef, researcher at TU Delft. He mentioned research he is involved in that touches upon a similar topic. Research is carried out by a consortium of TNO, TU Delft, University of Twente, Municipalities of Amsterdam and Rotterdam, and various local companies. The research is committed to making construction logistics more sustainable, predictable, and efficient. The research assumes that there is no example known today that uses a dynamic digital planning tool that connects between BIM, the construction planning and logistics through the entire supply chain of simultaneous projects in urban areas. So, a vision has been created for the development of a Construction Logistics Control Tower (CLCT). The CLCT research contributes to developing insight into the reduction of operational logistics costs and increasing sustainability of the logistics process within the construction industry. These topics are closely related to digitally managing resources in the construction industry. Therefore, being a suitable match for my graduation thesis. Consequently, it can be considered as a contribution to the larger research concerning the CLCT. This thesis develops a proof-of-concept for managing resources between projects, based on digital connections between resource data. It further extends the knowledge concerning the digital management of resources within construction logistics.

Acknowledgement

During this thesis, I have learned a lot, and I would like to take this opportunity to express my gratitude to the people who have supported me during the last stage of my university adventure.

First and foremost, I would like to thank my mentors from TU Delft, Ruben Vrijhoef, Sander van Nederveen, and Paul Chan. Ruben's passion for the topic and his strong motivation have been a constant source of inspiration. Sander's guidance and support throughout the feedback sessions have been invaluable, and Paul's constructive approach towards writing a proper research paper has helped me tremendously.

I would also like to thank Rob Vos and Philine Goldbohm for giving me the opportunity to do my graduation at ‘dutch process innovators’ (dpi). Rigt Venema's supervising support during the research has been invaluable, and I am grateful for his guidance and advice. Additionally, I would like to thank all my colleagues at dpi who were able to help and made me feel welcome in their office.

Finally, I want to express my gratitude to my family and friends for their unwavering support and encouragement throughout my academic journey. Their belief in me has been an essential factor in my success, and I am grateful for their constant love and support.

Once again, thank you to everyone who has supported me throughout this thesis. Your guidance, encouragement, and unwavering support have been instrumental in helping me achieve my goals, and I am truly grateful for everything that you have done for me.

Management Summary

Keywords

Construction Resource Management, Logistics, Resource Allocation, Construction Logistics, Supply Chain Management, Information Technology, Resource-driven Planning, Information Sharing, Collaboration

Introduction

The construction industry faces challenges such as complex projects, tight budgets, and supply chain issues. Efficient resource management has become critical to achieving project goals. Resource management involves the allocation of resources to achieve the greatest organizational value. Effective methods of resource allocation have been studied, and their implementation can boost project performance. Logistics is also crucial in the construction industry. Compared to other industries, construction logistics has unique characteristics due to site location, material intensity, consecutive order of activities, and the fragmented nature of the industry. Building Information Modelling (BIM) is a 3D model-based process that has become a catalyst for the adoption of new technologies within the AEC industry. BIM can assist in various construction processes, but its use is still limited due to the fragmented nature of the industry. The industry uses a variety of Enterprise Resource Planning (ERP) applications that are not yet integrated with BIM. ERP can be used during the construction phase to reorganize and integrate business processes, reduce costs, and improve quality.

The present-day construction resource management in urban areas of the Netherlands raises concerns about its environmental impact due to various events such as the shortage of housing, a high demand for maintenance of infrastructure, and the significant role of the construction sector in carbon and nitrogen emissions. To address this issue, there is a need to optimize the management of resources efficiently between projects. The core problem is the insufficient optimization of resource management between projects, resulting in more traffic, higher emissions, and higher demand for energy, which can be prevented by linking projects and applying program management techniques. However, the complexity of construction projects and the lack of a common planning language and sufficient digital infrastructure hinder the optimization of resource management. Nevertheless, research has shown that considerable gains can be made by reducing transportations and emissions through measures such as building hubs, bundling, building containers, traffic measures, and transport by water. These measures can save the construction industry money, improve air quality, and decrease emissions.

The aim of this study is to develop a proof-of-concept for managing resources between construction projects using digital connections between resource data. The goal is to optimize information sharing between different companies to reduce urban city traffic, energy consumption, and emissions, while also being practical and easy to implement. The final product is a proposed solution designed to reduce the number of necessary transports.

Theoretical Background

The author's interest in the topic of digital resource management in the construction industry is driven by the lack of adequate IT tools to support the industry, improve efficiency and reduce environmental impact. The theoretical research in this paper focuses on digitalization, resource management and interorganizational collaboration, and critically evaluates previous studies to identify gaps and determine the next steps.

Digitalization refers to the increased use of digital or computer technology in an organization, industry, or country. The construction industry, being the largest consumer of raw materials worldwide, stands to benefit greatly from digitalization. However, the industry is slow in

adopting new technologies compared to other industries due to technical challenges, such as the lack of national standards, high costs of application, lack of skilled personnel, organizational issues, and legal issues, and the fragmented nature of the industry. Building Information Modelling (BIM) and digital twins are two key technologies that can help overcome these barriers. BIM is a digital representation of a built asset that contains in-depth information and can be applied throughout the whole lifecycle of an asset, while a digital twin is an up-to-date representation of a physical asset in operation, which can predict future behaviour and optimize operation.

Supply chain management, program management, and consolidation centres are important theories and techniques for managing resources, particularly in the construction industry. Supply chain management involves the planning and management of activities involved in sourcing and procurement, conversion, and logistics management activities. Program management is the management of a set of related projects in a coordinated fashion to obtain control and benefits. Consolidation centres are logistic facilities that can reduce vehicle movements and emissions. While these concepts show promise in improving resource management in construction, there are challenges to their implementation.

Interorganizational collaboration in the construction industry is where two or more independent organizations work together. Collaboration can take place vertically or horizontally, and it involves the sharing of information, resources, and orders. The research highlights the importance of information sharing, which is crucial for planning, cost savings, and achieving higher quality and service levels. Interoperability is also an essential aspect of collaboration, as it ensures that different systems and products work together seamlessly. A resource pool can be created within an urban area to manage resources efficiently, allowing other projects to use resources based on their availability. Finally, the paper discusses the importance of using the latest IT for real-time information sharing and for automating calculations to provide better predictions and solutions.

The literature highlights the slow adoption of digitalization in the construction industry due to technical challenges and integration issues. Resource management systems tend to be expensive and not perfectly suitable for unique construction projects. Interoperability issues exist in information sharing between organizations, but the use of standards like IFC can help. The Construction Logistics Control Tower is suggested as a solution to improve information exchange. The hypothesis is that implementing a centralized resource management system and strategies for resource sharing can optimize resource management between multiple urban construction projects, ultimately reducing the number of empty vehicle movements.

Methodology

The framework for this research includes the research design, Unit of Analysis, and research methods. The research design chosen is a cross-sectional design, which involves collecting data from multiple cases at a single point in time to detect patterns of association. The Unit of Analysis is the sample of transport records from construction projects of quay walls and civil works in Amsterdam, which are adjusted in time to enable the cross-sectional design.

The Unit of Analysis for this research is the 'Samenwerkingsovereenkomst Kademakers' (SOK), which includes several construction projects in and around the Wallengebied in Amsterdam. The long-term collaboration and repetitive work made the renovation of quay walls a suitable Unit of Analysis to investigate a new approach to reduce operational logistics costs and improve sustainability. Logistics data is gathered from different contractors to find similarities between transports that could have been bundled. The research demonstrates that transport could have been reduced through information sharing between projects. Stakeholders in the project have expressed a desire to start small and expand while going, in line with the Minimum Viable Product (MVP) methodology.

The research is divided into three phases: Problem Investigation, Solution Design, and Solution Validation. The Problem Investigation involves creating a frame of reference, conducting an in-depth problem analysis, and developing a hypothesis. The Solution Design focuses on testing the hypothesis through semi-structured interviews, company visits, focus groups, and a requirements analysis. Data is gathered through content analysis and transformed into a uniform set of samples for minimalist discrete event simulation. The Solution Validation verifies the interventions' genuine effect on the total distance of transports and reduces the unused tonne-kilometres value through increasing vehicle load factor or reducing transport kilometres.

Analysis

The analysis follows the concept of Smart Urban Construction Logistics and various strategies that the construction industry can employ to reduce its environmental impact. Resource logistics can be divided into two categories: stocks & corridors. Stocks are the inventories that are present on a specific location, and corridors are the routes between stock locations. The chapter then focuses on four interventions: shared import/export corridor, direct exchange between projects, urban stock location, and cross-docking. These interventions aim to reduce the total travelled distance of vehicles, minimize carbon emissions, and optimize resource utilization. Overall, it promotes a more sustainable approach to construction by optimizing resource management strategies, promoting efficient use of materials, and reducing waste.

The Unit of Analysis includes three case studies, named Gillis, Singel, and Herengracht. Originally, the plan was to analyse three quay wall projects from contractors in the SOK agreement, but due to data access constraints, alternative civil work projects in Amsterdam were selected. The Singel project involved reinforcing the quay wall with a temporary emergency solution and transporting materials via barges. The Herengracht project underwent a complete renovation with a new quay wall constructed using steel piles and prefabricated concrete walls. Materials were transported via barges and a hub in the port of Amsterdam. The Gillis project focused on the redesign of a street and used a tipper truck for material transport. Standardized materials were provided by the municipality's materials office to ensure compliance with city requirements.

The first analysis engaged on finding the potential for resource optimization in construction logistics, which is focused on identifying what materials are being transported and how efficiently they are being transported. The data sample used is from three construction projects over three months, and the materials are grouped into larger categories to understand material flows. Load factor, the ratio of the average load to the total vehicle freight capacity, is used to determine efficiency, and a load factor of below 60% is identified as the potential for improvement.

The study applies the interventions to the transport records. For each record, the study checks whether a particular intervention could be applied, and if the load factor was less than 60%, potential optimizations were identified. Transports that occurred around the same time were also considered, and if other transport records from the same time period did not allow for an intervention, it was deemed not possible to apply. The potential interventions that could be applied to the transport were then listed.

Additionally, a requirements analysis for a centralised management system is conducted. The hierarchy followed in establishing the requirements is described, starting with high level business requirements, followed by user needs, and then system requirements. The sources of user needs are discussed, including focus groups, expert opinions, and interviews. The business requirements for the construction logistics control tower (CLCT) project are discussed. The goal of the project is to reduce traffic caused by the construction industry by optimizing resource management between multiple urban construction projects. The CLCT will serve as an instrument for tactical and operational planning, operational control and monitoring, and supervision of the construction logistics process of one or more construction projects in a region. The system is expected to help in the management of multiple urban construction projects, and there are multiple users of the system, primarily the contractor. The user requirements were determined by conducting semi-structured interviews with two SOK contractors, Beens Groep and H. van Steenwijk, and PK waterbouw, the carrier. The user requirements were determined using a prioritization hierarchy, which focused on the most important requirements from a contractor's perspective. The contractors would like to have more information easily accessible to optimize their operational efficiency, such as the insight in transports of surrounding projects to visualize where and how transport can be optimized, insight in availability of resources, registering material and waste to predict required transports, and implementing restrictions in the area. Moreover, contractors would like to add emission calculations to the system, which would help in automatically predicting and tracking emissions within the city. There were three functional requirements identified: (1) the system must allow the user to share data, (2) the system must make relevant data from other users visible, and (3) the system must gather, process, and visualise information to generate new insights for all users.

Results

The material flows of urban projects show an indication of critical logistics resources, and the load factor of vehicles gives insight into where improvements can be made. Ground transports have the highest load factor (88%) and a reasonable number of transports (40%). Empty transports make up 28% of all transports, mainly caused by vehicles returning empty.

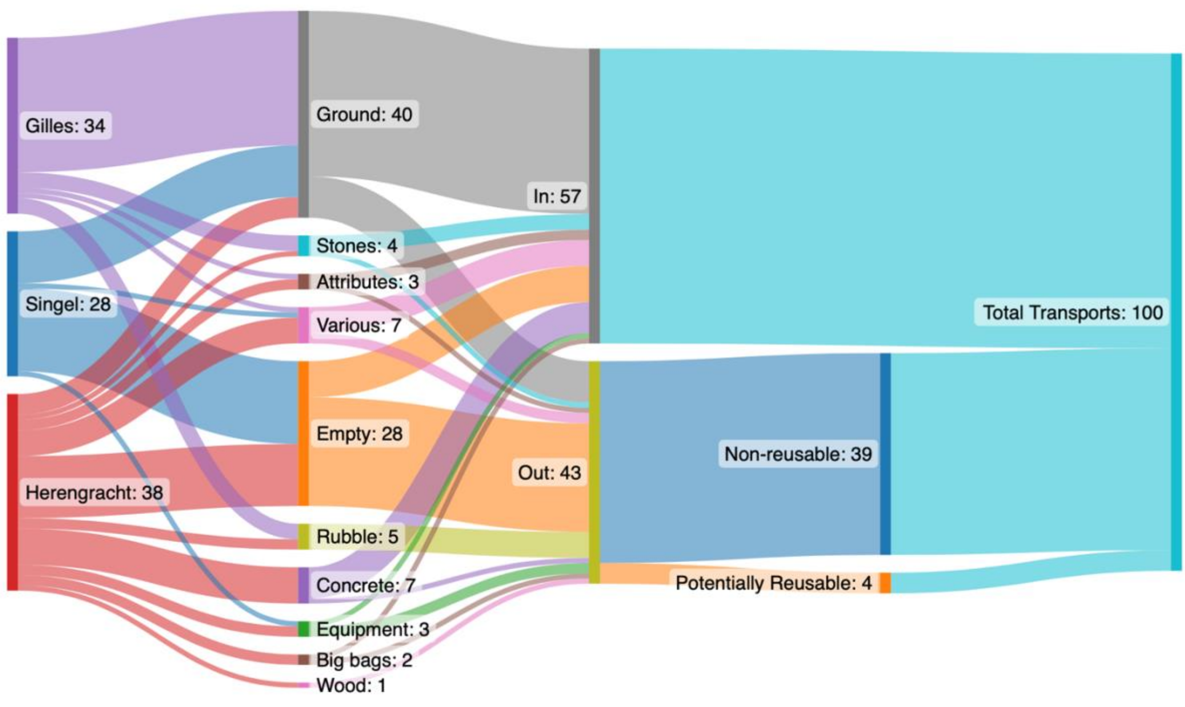

Figure S. 1. Sankey Diagram of Transport Records (numbers in %)

The load factor measures the utilization of available capacity, and a higher load factor indicates more efficient use. Outgoing empty transports (see Figure S. 3) and transports with a load factor below 60% indicate potential for optimization. In contrast, most ingoing transports (see Figure S. 2) are loaded efficiently, but 12% are empty and 11% are below 60% load capacity.

Categories such as 'Equipment', 'Stones', 'Wood', and 'Various' have lower load factors and are less efficient (see Figure S. 4). Imbalanced in and outgoing flow can result in empty transports due to unequal supply and demand. The current data cannot completely solve this imbalance. The transport records indicate that for imported goods, over half of the transports show potential for applying one or more interventions, resulting in 12% of all import transports being suitable. For exported goods, mainly empty transports that return from project sites, there is a larger potential, but there are fewer possibilities for interventions due to a lack of transports exporting goods around the same time.

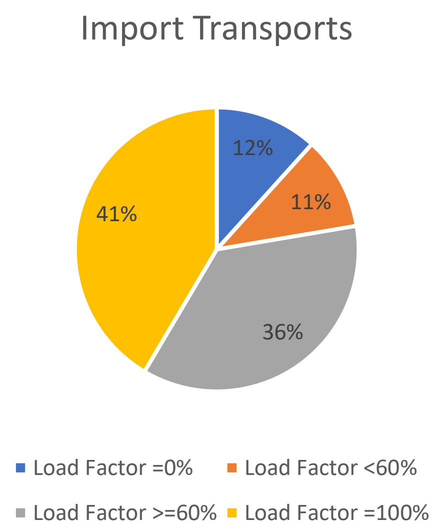

Figure S. 2. Distribution of Load Factors for Ingoing Transports

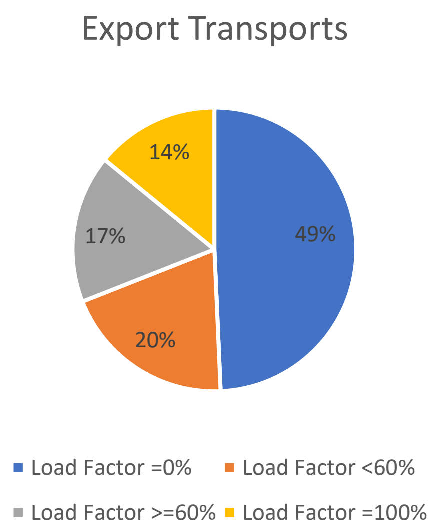

Figure S. 3. Distribution of Load Factors for Outgoing Transports

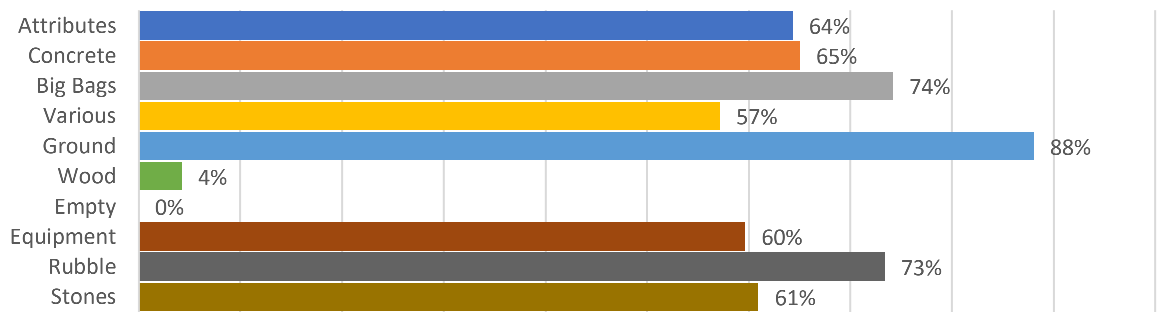

Figure S. 4. Load Factor per Category

Findings

The contractors interviewed for this research, who are involved in small to medium-sized infrastructural projects, have a less advanced approach towards digitalization. There is no specific software used for logistic planning, and 3D models are not being used. Communication between contractor and third parties like suppliers or logistics services is typically done through phone calls, resulting in the loss of data. There is also no standard in keeping track of transport records of projects, with data being quite rough and not specific enough. None of the contractors mentioned that they are currently applying optimizations, other than logical thinking. The experience gained from the interviews, meetings, and gathering of the data agrees with the written literature about digitalization in the construction industry, indicating that the level of digitalization in the industry is lacking behind other industries. However, this group of contractors cannot be generalized for the whole industry.

The construction industry lacks optimization in resource management due to fragmentation, short-term goals, limited technology, lack of data, and limited collaboration. Collaboration is seen as a solution, and critical logistics resources for urban infrastructure projects include equipment and vehicles, non-bulk materials/waste, and storage space. Analysis reveals the potential for bundling non-bulk materials, addressing the imbalance of material streams, and efficiently using limited storage space. The study proposes a centralized system to manage critical logistics resources in the construction industry, which requires transportation and material data. However, data recording is insufficiently digitalized in smaller sized construction companies, so data gathering and recording on a large scale is required to optimize logistics. Additional data, such as inventory management, historical data, real-time tracking, customer and supplier data, and data analytics, could be considered to extend the application of a centralized system.

Conclusion

The study focuses on optimizing logistics in the construction industry in the Netherlands to reduce emissions. The study emphasized the benefits of collaboration among different construction projects and proposed a hypothesis that a centralised resource management system can optimize resource usage and reduce environmental impact. By analysing the construction logistics of three projects in Amsterdam, the study demonstrated that a centralised system for logistic resource management can be employed to reduce traffic required for construction projects, optimize resource usage, and potentially improve the balance between ingoing and outgoing transports. The study also highlighted the challenges in data capturing and the need for a unified digital system for logistic data. The study concludes that a centralized system for logistic resource management can provide insight into transport data and could reduce traffic caused by construction projects through facilitating smart interventions.

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1. Introduction

This chapter introduces the topic of this research. It describes the issues that currently exist in construction resource management and provides additional information to the reader to develop a frame of reference. The subsequent section presents the problem statement, followed with the aim and research questions. This chapter ends with a section about the organization of this research.

1.1. Frame of Reference

This section contains an introduction to the key topics of this research: resource management and logistics in the construction industry. These topics are described to develop a frame of reference for the reader. The information contributes to a better understanding of the problem statement in the subsequent section.

Construction projects have become increasingly complex (Cristóbal, Carral, Diaz, Fraguela, & Iglesias, 2018). Companies are facing the challenge to deliver projects within time and budget, adhering to environmental measures while still making a reasonable profit margin. On top of that, the industry is currently dealing with supply chain issues due to a growing demand for materials and a worker shortage. Efficiently managing resources has become beyond critical. A resource is an entity that contributes to the accomplishment of project activities. Construction projects are exploiting many resources, such as manpower, material, and equipment. The resource-driven nature of construction management makes resource management an important task for managers. The importance of it has been highlighted in numerous literature (Karaa & Nasr, 1986; EL-Rayes & Moselhi, 2001; Tommelein, Riley, & Howell, 1999). Construction resource management is the process of allocating resources to achieve the greatest organizational value. To complete a certain activity in a project, resources are required. The availability of the resource is therefore directly related to time and money (Nagaraju & Reddy, 2012). There are multiple methods known to effectively allocate resources to construction activities. These methods demonstrate how resource-driven planning could boost project performance and provide a foundation for construction resource management (Park, 2005).
During the execution phase of a project, resources need to be moved from one location to the other. This is where logistics come into play. The term *logistics* dates to the late 19th century when it was first recorded in the Oxford English Dictionary. Further research however indicates that the term was already being used early 19th century. At that time, logistic management was applied in the Napoleonic Wars (Sullivan, Barthorpe, & Robbins, 2010). Nowadays, logistics is defined by the Council of Logistics Management as "the process of planning, implementing and controlling the efficient, effective flow and storage of goods, services and related information from the point of origin to the point of consumption for the purpose of conforming to customer requirements." In other words, it is the management of all activities that facilitate movement and the coordination of supply and demand. This definition also applies for construction logistics. For construction projects there exists demand for several materials and resources that need to be delivered on the right time and location. Compared to other industries, the construction industry has some characteristic differences that shape construction logistics (CIVIC, 2018): 1) Construction projects are never the same due to its unique site location. 2) The construction site is material intensive, and the supply of material is irregular due to different phases of the construction. 3) Activities usually take place in consecutive order, which highlights the importance of precise planning. 4) And finally, there is the fragmented nature of the construction industry. In construction projects, there are many companies, suppliers and

logistics services involved that work together in temporary consortia. Each company has a different way of working which makes it difficult to collaborate with each other.
Nevertheless, the construction industry is in the middle of a paradigm shift. Building Information Modelling (BIM) has become the catalyst for the adoption of new technologies within the AEC[1] industry. BIM is a 3D model-based process that gives AEC professionals the insight and tools to integrate design and planning, so the industry can more efficiently plan, design, construct, and manage buildings and infrastructure (Autodesk Inc., 2022). Adding to that, it is a virtual platform that contains graphical and non-graphical data (Gaetani, Mert, & Migliaccio, 2020). BIM has an in-depth relationship with scheduling and can be directly linked with each other, known as 4D-BIM. This enables 4D simulations of the building execution which can detect clashes in the scheduling (Hardin & McCool, 2015). BIM enables digital collaboration on the built environment. In the construction phase, BIM can assist in several processes, but its use is still limited due to fragmented nature of the construction industry. The industry uses a variety of Enterprise Resource Planning (ERP) applications; however, they are not yet broadly integrated to BIM. ERP is commonly used in the manufacturing industry to digitally support all processes within an enterprise. ERP can be used during the construction phase to reorganise and integrate business processes, reduce costs, and improve quality (Hewavitharana & Perera, 2018).

1.2. Problem Statement

Present-day construction resource management raises concern about the environmental impact in urban areas in the Netherlands. Various events are currently taking place which are the root cause for these concerns. A growing urban population and a change in the size of households is causing a shortage in the housing market which leads to an increase in new urban construction projects (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2020). On top of that, there is a high demand for maintenance on already existing infrastructure. An example is the overdue maintenance of bridges and quay walls in Amsterdam (Gemeente Amsterdam, 2019). These events create that the construction sector is responsible for one third of the road transport in the Netherlands. Transport is causing carbon and nitrogen emissions, which both play a significant role in global climate change. To address these emissions, governments are sharing their ambition to improve local air quality[2] and reduce their carbon footprint[3]. The characteristics of construction logistics and the environmental impact of the construction industry are adequate reason to speed up the implementation of innovations and new technologies. Recently, there is growing acknowledgement of the importance of managing resources efficiently to deal with the sustainability challenge. Optimizing how construction resources are being managed is one way to contribute to the ambitions.
Studies on managing resources have so far emphasised what goes on within a single project. Tools like BIM and ERP are slowly being adopted in the construction industry, improving the efficiency of projects. However, we know far less about how to manage resources between projects. Because we know so little about it, the applicability is also limited. Therefore, the core problem can be defined as the insufficient optimization of resource management between projects. The effects of this are that there is more traffic than necessary. This results in higher emissions, nuisance, and a higher demand for energy. Also, the limited number of resources could be insufficient to meet the current high demand in construction. Furthermore, transport costs money. Optimizing transportations could lower the operational costs of contractors.

[1] Architecture, Engineering and Construction
[2] Schone Lucht Akkoord
[3] Klimaatakkoord

These effects can be prevented by linking various projects with the sales and operations planning of suppliers. When projects of similar nature take place in each other's proximity, a program management approach can be applied. Program management uses techniques that allow organizations to run multiple related projects simultaneously and obtain significant benefits from them as a collection (Haidar, 2016). Considering nearby projects as a program by linking information, contributes to an optimized use of resources across projects. Though, sharing information and collaborating between different parties requires a certain digital infrastructure which currently is not widely applied in the construction industry.
A cause of this is the complexity of construction projects. Construction projects are organised in such a way that all expenses must be booked on a single project. From an accounting point of view, allocating costs over several projects is often difficult. Additionally, there are multiple stakeholders involved in a construction project (e.g., contractors, suppliers, and logistics services). This makes it difficult to optimize resource management. The construction industry would require developing a common planning language to facilitate coordination. Current ICT solutions are too fragmented, incomplete and do not provide sufficient support for construction logistics (de Bes, et al., 2018). Figure 1 represents the problem statement by means of a problem tree, containing the core problem, the effects that the problem is causing, and the roots of this problem.

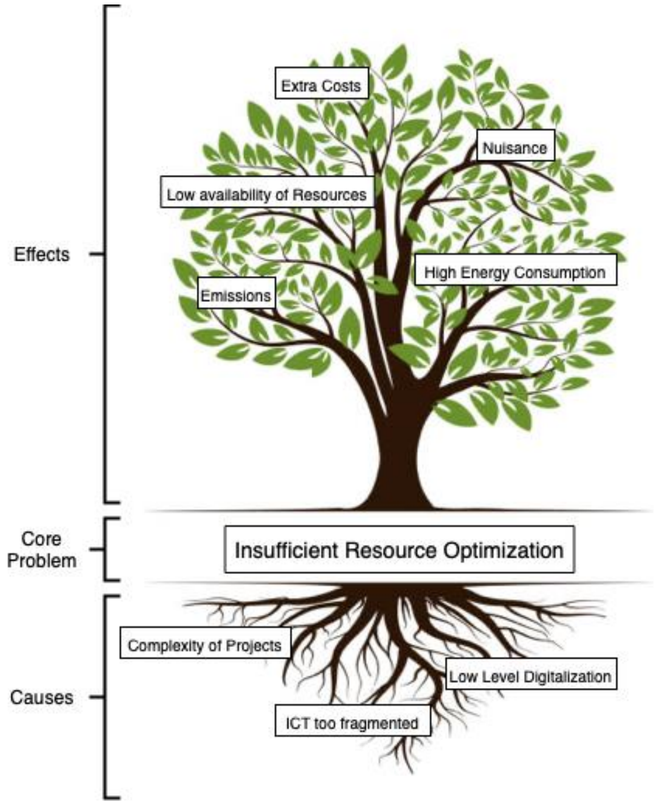

Figure 1. Problem Tree (own illustration)

Recently, research institutes, governments, universities, and the construction industry in the Netherlands have been conducting research into new concepts for construction logistics (de Bes, et al., 2018). The research has revealed at nine pilot projects in urban areas that considerable gains can be made in terms of savings on logistics costs and construction time, better flow, less harmful emissions, and less nuisance for public environment. These studies have so far focussed on gaining insight into reducing transportations and emissions caused by construction logistics. Several measures are conceivable for sustainable construction logistics, such as building hubs, bundling, building containers, traffic measures and transport by water (van Rijn, 2020). Experiments applying these measures show a significant reduction in the number of rides required. Saving the construction industry money, improving air quality, and decreasing emissions.

1.3. Aim

Therefore, in this study, the aim is to create a proof-of-concept for managing resources between projects, based on digital connections between resource data. This research builds upon earlier research and addresses the high contribution of construction logistics in urban city traffic by optimizing information sharing between different companies. By reducing traffic, the energy consumption and emissions can be reduced, as well as nuisance. The solution should be practical and easy to implement on short notice without requiring many resources. In other words, the final artefact of this research is a proposed solution that would reduce the number of transports needed.

1.4. Research Questions

To contribute to the aim of this research, the main research question has been formulated as follows:

How can resource management be optimized between multiple urban construction projects?

The research is subdivided into three parts: the Problem Investigation, the Solution Design, and the Solution Validation. The sub-questions reflect to these parts of the research. The Problem Investigation provides insight to the current approach of resource management and expose any barriers that contractors might experience. Additionally, the availability of logistics data is explored. The corresponding sub-question for this part is:

> RQ 1. *How are contactors currently managing resources?*

Secondly, the Solution Design demonstrates the inefficiencies within resource management. It points out where the inefficiencies are happening to be able to propose optimizations. The sub-questions corresponding to this part are:

> RQ 2. *What are critical logistics resources of urban (infra) projects that should be managed collectively?*

> RQ 3. *Which information/data is required to manage critical logistics resources digitally?*

At last, the Solution Validation is where the proposed optimizations are validated. This part demonstrates the impact and feasibility of the optimizations. Besides it is validated if the implementation meets the users' needs. The sub-questions are:

> RQ 4. *Which results can be achieved through the process?*

> RQ 5. *Is the implementation what the user wants?*

1.5. Research Organization

This graduation research is performed in partial fulfilment of the requirements for the degree of Master of Science in Construction Management and Engineering at Delft University of Technology. Specifically focussed on the field of Digital Design & Asset Management. This thesis is conducted in collaboration with 'dutch process innovators', a consultancy and project agency for construction, infrastructure, energy, and industry. The company focusses on the entire life cycle of assets and on all processes that are required for demonstrability, optimization, and innovation. From their part, Rigt Venema has been the supervisor during this internship.

The main supervisor is Ruben Vrijhoef, researcher at the Faculty of Architecture and the Built Environment at TU Delft. He is involved as researcher and author in the research towards sustainable construction logistics. His expertise in supply chain management forms the basis for this research.

The second supervisor is Sander van Nederveen, assistant professor at the Faculty of Civil Engineering and Geosciences at TU Delft. His main activities are teaching and research in integrated design and information systems for construction. Which makes his expertise on this topic more than suitable for the development of a proof of concept for the digital management of resources.

The chair of the graduation committee is Paul Chan, Professor of Design and Construction Management at TU Delft. His knowledge on inter-organization collaboration in the construction industry complements this research.

2. Theoretical Framework

My interest for this topic has been fuelled by the lack of good IT tooling in the construction industry, in this case to support dynamic digital resource management. Proper tools could help improve the efficiency of construction management in terms of time and money, but also in terms of environmental impact by reducing transportation. Overall, it could contribute to optimizing processes that yet are not making use of digitalization. Once information is digitally stored and is related to other data, the right optimizations can be made that takes these relations into consideration. To fully understand where this is heading, this chapter contains the theoretical research. When deconstructing the aim of this research, there are three concepts represented. The first section in this chapter evaluates the theory behind digitalization in the construction industry. The second concept is resource management, and the third concept is interorganizational collaboration. In this chapter a critical evaluation of previously published studies in this research area is provided. It explores what has been written about the topic to highlight a gap and to determine the next step.

2.1. Digitalization

Digitalization is the adoption or increase in use of digital or computer technology by an organization, industry, or country (OED Online, 2016). It is of importance for businesses to continue to develop and to optimize their processes. Digitalization has several advantages for the construction industry and other industries in general (Parusheva, 2019). It gives the opportunity to increase productivity and efficiency, speed up construction activities, safe time in the implementation of construction projects and adhere to construction schedules. On top of that it contributes to a higher quality and safety, and improved design of buildings. Considering that the construction industry is the largest consumer of raw materials worldwide (Parusheva, 2019) and a major contributor to a country's economy (Hossain & Nadeem, 2019), it highlights the importance of effective management in the construction industry.

Nevertheless, the construction industry is not adopting to new technologies as fast as other industries (Hossain & Nadeem, 2019). Studies indicate that labour productivity in the construction industry has not kept pace with the overall economic productivity, the industry is one of the least digitized (Agarwal, Chandrasekaran, & Sridhar, 2016) and spending on research and development has been lacking behind compared to other industries (Parusheva, 2019). The slow digitalization of the industry is caused by technical challenges that specifically play a role in the construction industry. A challenge is triggered by the different levels of digitalization amongst smaller companies, like subcontractors, who typically don't have the necessity to invest in new technologies. Despite the Covid-19 crisis, European construction companies are doing rather well and are making a fair profit (van Sante, 2022). Companies consider the investment as a risk and prefer to wait. However, companies that did adopt to new technologies have been using many systems which are difficult to connect and integrate with other systems. Different systems throughout the building process are being used which causes problems to distribute the data inside and outside the company. Also, a shortage in employees with sufficient knowledge in the field of ICT and experience in the construction sector is not helping to the development of new tools.

2.1.1. BIM

As shortly described in the previous chapter, Building Information Modelling is a digital representation of a built asset, which contains in depth information of the asset. BIM uses a three-dimensional geometrical model to display building components. Besides the geometry, the model also contains non-physical objects (e.g. schedules). BIM uses Object-Oriented Programming, meaning that the model consists of objects. An object can also contain non-

geometrical information (e.g. costs, manufacturer, supplier). The objects can be categorized into classes which makes them easier to be gathered. Furthermore, objects can interact with each other, and developers are able to create attributes and behaviour which makes it possible to program how objects are related and interacting with each other (Millman, 2019). The first and foremost use of BIM is 3D visualisation. 3D Visualisation contributes to a better understanding of the asset that is going to be build. Still, BIM is more than 3D visualisation. It is also used for construction sequencing, code reviewing, cost estimating and clash detecting (Azhar, 2011). Besides, it is a single source of truth that contains all kinds of information. This makes BIM suitable to store and transfer data between different collaborating parties within the project.
BIM fulfils a more profound use of computer technology, which can be applied throughout the whole life cycle of an asset. It improves the coordination of design activities, integrates simulations, it structures and controls the construction process, and enables efficient handovers between actors (Borrmann, König, Koch, & Beetz, 2015). In the AEC industry, the use of BIM has established results like cost and time reductions, improved communication and coordination, and quality improvements (Bryde, Broquetas, & Volm, 2013). These advantages ensured that many construction companies around the world are using BIM. Nonetheless, there are still barriers to overcome. The fragmented nature of the construction industry weakens the widespread use. Compared to other industries, the continuous use of digital information throughout the entire construction process is lacking behind and valuable information gets lost in between handovers. Liu et al. (Liu, Xie, Tivendal, & Liu) have summarized 5 barriers in BIM implementation: 1) lack of national standards, 2) high costs of application, 3) lack of skilled personnel, 4) organizational issues, and 5) legal issues. Costs being the most significant barrier, particularly for smaller sized companies. Another significant barrier this research touches upon, is the limited information sharing in BIM, caused by the lack of national standards. The scattered characteristic of the industry has created a lack of interoperability between different applications of organizations. This barrier will be discussed later.

2.1.2. Digital Twin

After a successful implementation of BIM, the next step towards automation is the creation of a digital twin. A digital twin is an up-to-date representation of an actual physical asset in operation. As a representation of an asset in operation, a digital twin reflects the current asset condition and includes relevant historical data about the asset. Digital twins can be used to evaluate the current condition of the asset and, more importantly, predict future behaviour, refine the control, or optimize operation. A digital twin can model: a component, a system of components or a system of systems (The MathWorks, Inc., 2022).

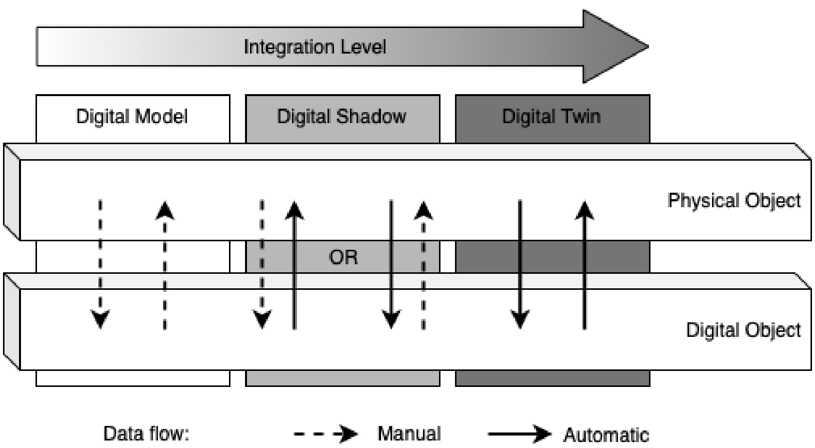

Figure 2. Integration Level Digital Twin (own)

Figure 2 displays the integration level of a digital model, digital shadow, and a digital twin. In a digital model the physical condition of an object does not automatically influence the digital condition of the object, and vice versa. A manual change is necessary to update either of the two. In a digital shadow at least one of the data flows is automatic. A change of the physical object automatically influences the digital model, or the other way around, but not both ways. In case of the digital twin, data flows both ways automatically (Belfadel, Horl, Tapia, & Puchinger, 2021). In the case of city logistics, the digital twin can be used as a decision-support tool for various scenarios to control traffic noise, congestions, or emissions. The author (Belfadel, Horl, Tapia, & Puchinger, 2021) gives the example of cordon pricing, where the price to enter a certain area can be altered depending on the hour, such that commercial vehicles operating in the area shift to cheaper hours, reducing congestions. By applying multiple scenarios, an optimal balance can be achieved between different KPI's[4]. The application of digital twins might not be the scope of this research, nonetheless it is relevant to keep future potentials in mind while designing the foundation. Designing towards a digital twin would be the optimum case.

2.2. Resource Management

Now that the theory and the importance of digitalization is clarified, it is important to know which theories and techniques exist concerning resource management. The term 'resources' is quite a broad term. In this research mainly material and equipment is considered.

2.2.1. Supply Chain Management

Part of managing resources, is managing the supply chain of those resources. A supply chain consists of two or multiple, legally separated organizations, which are connected by means of material, information, and monetary flows (Stadtler, 2008). A definition for the term Supply Chain Management (SCM), provided by the Council of Supply Chain Management Professionals, is '*The planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third- party service providers and customers*'. A common tool used in SCM, mainly in the manufacturing industry, is Enterprise Resource Planning (ERP). Shi and Halpin (Shi & Halpin, 2003) describe the application of an ERP system in the construction industry, stating the following. ERP provides a general working platform for a company to facilitate its main business management purposes. The platform is based on a single database where users from different divisions can communicate and share information. However, within the construction industry, ERP systems are not widely implemented yet. Most construction firms are too small to afford the implementation of an ERP system. Besides, it does not meet the needs of the construction industry because it is primarily developed and standardized for the manufacturing industry. The authors proposed several basic features for a Construction ERP: Project-oriented, integrated, paralleled and distributed, open and expandable, scalable, remotely accessible, transparent, reliable and robust. An ERP architecture focused on the construction industry could limit the extensive size of the system, together with the costs for development and implementation.

Previous study (Oosterwijk, 2017) has been dedicated to the topic of SCM through BIM. With BIM, logistic information can be integrated with computational models to support companies in managing their supply chain and inventory. The use of 4D-BIM has a positive effect on logistics. It positively contributes to the productivity of the assembly, reduction of inventories,

[4] KPI = Key Performance Indicator (variables to analyze performance)

and to streamlining material flows (Bortolini, Formoso, & Shigaki, 2015). The study (Oosterwijk, 2017) concluded that currently there is a disconnection between the logistic information and BIM. Current information processes are fragmented and uncoordinated. One of the reasons for that is the conservative attitude and the lack of insight in the information processes of the contractor. However, based on a case study, experts' opinion, and literature review, it showed that the adoption of BIM for the management of on-site construction logistics is financially, organizational, and socially feasible.

2.2.2. Program Management

Modern day management techniques, like Program Management, are not yet widely implemented in the construction industry as much as in other industries. Program Management is defined as "… the management of a set of related projects in a coordinated fashion to obtain control and benefits that would not be available if the projects were managed individually… Like projects, programs are a means of achieving organizational goals and objectives, often in the context of a strategic plan (Safari Tech Books Online and Project Management Institute, 2008)." An author who has dedicated research to applying Program Management for the construction industry, describes the term as follows (Delaney, 2016). "Construction program management is the practice of incorporating both strategic and tactical management techniques, on one or more projects, from inception to completion, to increase the likelihood of success." The author also highlights the difference between tactical and strategic thinking, which he states is the difference between project management and program management. Program management requires a higher level of thinking. Construction managers have decent tactical skills but lack strategic thinking, which makes them struggle as a program manager. In the case of this research, the organizational goal is to reduce traffic in urban areas caused by construction projects. By integrating Program Management into the solution space, strategic management can be applied that would increase the likelihood of success (Rahschulte, Waddell, & Martinelli, 2014).

2.2.3. Consolidation Centres

A concept that embraces the idea of program management are Consolidation Centres (CC's). From earlier studies and practical experiences in the Netherlands it appears that the concept of Consolidation Centres can contribute to the reduction of vehicle movements and consequently emissions (de Bes, et al., 2018). CC's are logistic facilities where construction materials are delivered for consolidation, classification, and delivery to the construction sites (see Figure 3. Logistics Chain Consolidation Centre). It would allow for optimized delivery at the construction site, fewer traffic congestions in urban areas, enhanced working circumstances, and reduced energy use and emissions (Muerza & Guerlain, 2021). In recent study (van Merriënboer & Rondaij, 2020) analysis has been done to determine the impact of CCs on the liveability in cities in the South Holland region in the Netherlands. With the application of a building logistics calculation model, it has been determined that there are up to 27% fewer journeys in the city alongside a reduction of 8 – 16% in emissions (CO_2, NO_x, PM_{10}). Applying CCs on a large scale would have the greatest added value. Preference is given to a limited number of large CCs over many small CCs. These are interesting studies; however, they do not yet describe *how* the concept is going to be implemented.

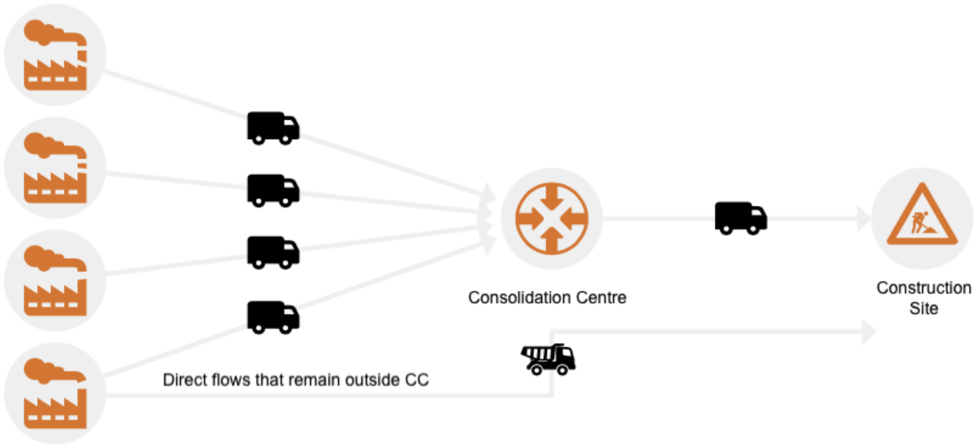

Figure 3. Logistics Chain Consolidation Centre (de Bes, et al., 2018)

2.3. Interorganizational Collaboration

The next concept to be discussed is the collaboration of two or more independent organizations. Collaboration takes place between different organization, during different time periods. Typical organizations during a construction project are contractor, supplier, and carrier. They hold different types of information, which is stored in their own databases and have their own way of working. This paragraph will address this topic by means of literature.

2.3.1. Sharing in Logistics

An improvement to the inefficient use of urban freight transport, is for companies to increase collaboration between each other. A distinction can be made between vertical and horizontal collaboration (Barratt, 2004). Vertical collaboration implies a cooperation between contractors, suppliers, and customers. Horizontal collaboration is defined as the combined practices between companies operating at the same level(s) in the market (European Union, 2001/C). These companies operate within the same transport segment and provide similar services. Consequently, they are each other's rivals. Aside from the reduced amount of traffic, there are still several reasons for companies to collaborate:

- Increases the company's productivity of core activities.
- Reduces the costs of non-core activities.

- Reduces purchasing costs.
- Offers better quality of service at lower cost.
- Specialize, while broadening the services.
- Enables contracts with large shippers.
- Helps to protect market share.

Three types of objects shared amongst companies are identified. The first is ‘order sharing’. This collaboration combines, shares, or exchanges customers’ orders. In this case the demand is shared. The second is ‘capacity sharing’. Here the transport supply is shared. This entails the temporary loan or borrowing transport capacity. The capacity could be defined in terms of load units, transport units, logistics facilities or storage capacity. The third type is ‘information sharing’. This is taking place when carriers share anonymized information with other partners. A possible application could be optimized parking management.

2.3.2. Information Sharing

Literature underlines the importance of information sharing (Syed Abdul Rehman Khan, 2019). The authors state that the planning process will be easier and more productive, to achieve higher quality, cost savings and service levels, if the participants of the supply chain know each other’s plans and are willing to collaborate. Information sharing can be improved by using the latest IT for real-time information sharing. However, without the willingness to share information with supply chain partners, goals cannot be achieved. Coming back to ERP systems, an ERP runs off a single source of information. Once information becomes available, it is available to all users. Information sharing eliminates the need to regenerate the same information in different offices and reduces the risk for human errors.

2.3.3. Interoperability

The ICT tools that currently exist in the construction industry are too fragmented and don’t work effortlessly with other tools. Interoperability is of high importance. It can be defined as the ability of a system or product to work seamlessly with other systems or products without requiring additional effort from the customer or user (Doumeingts, Müller, Morel, & Vallespir, 2006). The ability of a company to seamlessly interoperate with others largely determines the competitiveness of the company. BIM has become the standard platform in sharing information between different parties in a construction project. To solve the issue of interoperability in BIM, IFCs[5] have been established. IFC is a neutral and open file format for exchanging BIM-specific information between software applications (buildingSMART, 2022). There is an IFC standard for construction resources with predefined attributes that can be used to specify the resource. Additionally, logistics properties can be added to a BIM-object, such that connections can be made with logistic calculation models and planning tools (de Bes, et al., 2018).

2.3.4. Resource Pool

Within an urban area, a pool of resources can be created and managed through MS Project, a tool that is used for scheduling and cost control. Within the project planning, resources can be assigned to a task. The resource type can be divided into Costs, Material or Work. For the task ‘Excavating’ you typically would need an excavator. The resource excavator is created and assigned to the task ‘Excavating’. Within the resource information, the availability can be specified. By default, the resource is indefinitely available. However, this is not the reality. Sharing this information by means of a resource pool, would give other projects in the pool, the opportunity to use resources from (surrounding) projects based on their availability.

[5] IFC = Industry Foundation Classes

Changes in the availability of resources have an impact on the planning. Building materials could (temporarily) be limited due to supply problems, and machinery could suddenly break down. The impact of these events could be determined with the information that is there, but currently this is not happening automatically. If resource information is integrated with the project schedule, calculations can be automated and better predictions, choices and solutions can be provided. Overall, more control over the availability of resources would be made possible.
For example, consider the task 'Excavating'. Suddenly the excavator breaks down due to some issue which cannot quickly be resolved. The resource becomes unavailable. If no action is taken, and the task is on the critical path, there will be a delay. Because the company is collaborating in the resource pool, it is possible to see whether there is another excavator currently available at a nearby project. Also, materials can be assigned to an activity. This will generate an overview of all the material resources that are required on a specific day. Based on this information, a prediction can be made for the expected deliveries on sites. In the case of a resource pool through MS Project, there is no direct connection to BIM. The connection is made within MS project itself. This application illustrates how multiple project schedules can be combined to (re)allocate, manage, and optimize resource usage.

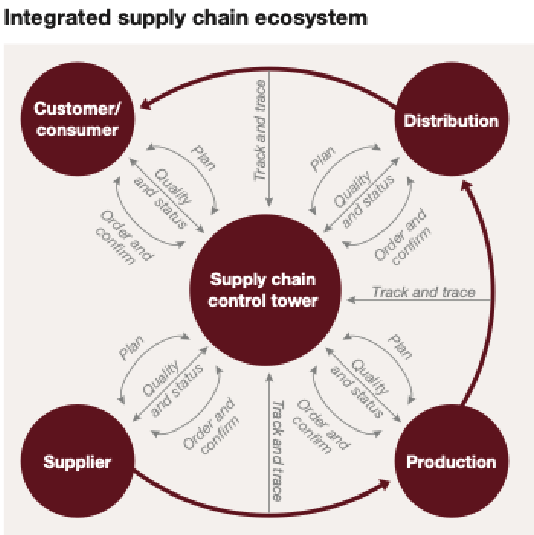

Figure 4. Integrated Supply Chain Ecosystem (Schrauf & Berttram, 2016)

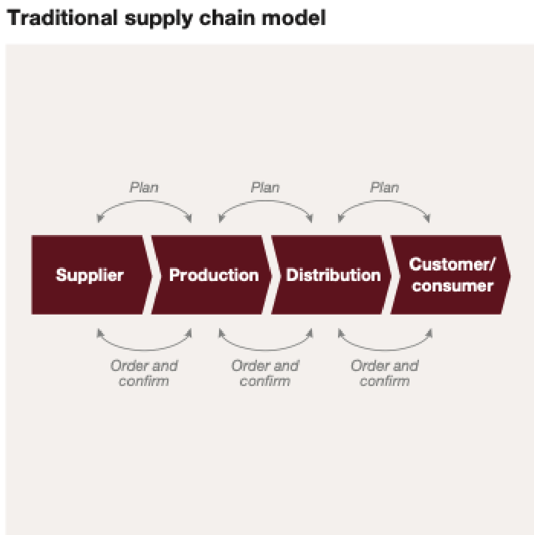

Figure 5. Traditional Linear Supply Chain Ecosystem (Schrauf & Berttram, 2016)

2.3.5. Construction Logistics Control Tower

There is a lack of coordination in construction logistics, particularly when multiple projects in a certain region are considered. Currently the construction industry is missing well-supported ICT for information exchange on the logistics process (de Bes, et al., 2018). Limited literature is dedicated to systems which coordinate construction activities and processes. A system that has been proposed in previous research is the construction logistics control tower (CLCT). A control tower is a central coordination system for multiple logistical chains (Vries, Rinsma, & Ludema, 2015). Focussing on construction logistics, a CLCT can be considered as a central node which monitors, plans, and coordinates logistical processes for one or multiple construction projects by integrating relevant information systems and data sources (Tesselaar, 2020). A visualisation of the central coordination system is provided in Figure 5. A traditional supply chain model, which is more linear, can be considered as a decentralised system and is visualised in Figure 5. The main difference between the two systems lies in the degree of authority and decision-making power held by the individuals or groups within the system. A centralised management system provides greater efficiency and consistency, while a decentralised management system offers greater flexibility and innovation (Luenendonk, 2019). Compared to a traditional supply chain model, the control tower creates a more integrated ecosystem with the control tower as the central point (Schrauf & Berttram, 2016).

The functionalities of a CLCT have been analysed and prescribed by several authors. De Bes, et al. (2018) summarized the functional requirements for the control tower in Table 1.

Table 1. Function Requirements CLCT (de Bes, et al., 2018)

1	**Transport planning** of the logistic supply and discharge flows (horizontal transport)
2	**Crane planning** (vertical transport) and dynamic synchronization of vertical and horizontal transports
3	Planning of **delivery windows** at unloading points, including issuing **construction tickets** for deliveries at construction site(s) and consolidation centre(s)
4	**Stock management** for keeping track of stocks at the hub and on the construction site
5	Planning **consolidation of transports** from different suppliers into composite logistic shipments (work packages)
6	Planning **preferred construction traffic routes** (the most suitable routes for construction traffic)
7	**Real-time monitoring of deliveries and transports** by carriers and suppliers on the construction site and 'en route', considering: • current traffic on the road using of real-time Floating Car Data. • current traffic measures that affect are within reach of the construction site.
8	Periodic monitoring (per day or week) of the **performance of construction logistics** on pre-selected KPIs, such as: transport trips, kilometres, CO2 emissions, load factor and more.

Tesselaar (2020) also summarised the functional requirements for a CLCT. These have been subdivided into three categories: the Information Hub, Planning and Routing, and Decision Making. The desired functionalities are provided in Table 2.

Table 2. preferred functionalities for a Control Tower

Planning and routing	– In- and outbound logistics, including waste transportation (T/O) – Real time monitoring/tracking, including estimated time of arrival (O) – Horizontal transport planning (T) – Planning of delivery time windows (T/O) – Consolidation planning (T/O) – Construction planning (S/T) – Vertical transport planning (e.g. crane planning) (T/O) – What moves where at what time, in which amounts (T/O)
Info Hub	– Preferred route information (S/T) – Process and performance monitoring (O) – Forecasting and scenario calculation (S/T) – Digital twin (S/T/O) – Collaborative information sharing (S/T/O) – Relation between construction and logistical schedules (T/O)

	– End-to-end visibility (S/T/O) – Inventory management (O) – Vehicle information (S/T/O) – Material properties (S/T/O) – Area information (S) – Costs of processes (S/T) – Site layout and management (S/T/O)
Decision Making	– Event management (T/O) – Self corrective actions and warnings (T/O) – Auditing and reporting (T) – Creating and sending of invoices (T/O) – Balance supply and demand of materials and equipment between projects (S/T) – Aligning projects with each other (S/T) (section 5.5) – Apply for permits and exemption papers, e.g., zone entry or (un)loading (T/O)

2.4. Conclusion & Hypotheses

In this chapter three main topics have been discussed: digitalisation, resource management in construction and interorganisational collaboration. Literature addresses the benefits of digitalisation and highlights the importance of it. The construction industry has been a slow adopter in terms of digitalisation. The construction industry has been ravaged by technical challenges like the different levels of digitalisation, integration issues between software and a shortage in employees.

The second topic explains about resource management in the construction industry. Literature indicates software systems to manage resources are nothing new. Yet such systems tend to be expensive and smaller construction companies are not able to afford it. Moreover, these systems are typically designed for manufacturing purposes. Construction projects tend to be unique, which causes these systems not to be perfectly suitable for construction projects. Another suitability issue described by the literature is the disconnection between logistics information and BIM. Nonetheless, different studies demonstrate the feasibility of connecting both. This section also introduced the use of consolidation centres for construction logistics in the Netherlands. Recent studies showed great potential to reduce vehicle movements by consolidating construction materials in a specific location before being delivered to construction sites.

The third topic dives into the collaboration between organisations, in this case horizontal collaboration. This is collaboration between parties that operate within the same segment, providing a similar service. Literature indicates that even though these companies are each other's rivals, collaborating has benefits for them. A particular form of collaborating is information sharing. This eliminates the need to regenerate the same information. However, the issue with information sharing is interoperability. Software between different companies is not always compatible with each other, which makes sharing information difficult. Within BIM a way to overcome this issue is the use of standards, like IFC. For the smaller construction companies, it would be necessary to establish these standards such that information sharing becomes less of a struggle. Currently, the industry is missing proper ICT tools for information exchange. The concept of a Construction Logistics Control Tower should fulfil this gap by becoming a central node and managing all information around construction projects.

Based on the literature, a first hypothesis for the main research question is provided in this section.

How can resource management be optimized between multiple urban construction projects?

The literature exposes the current possibilities in resource management and indicates that optimizing is not impossible. However, there are certain barriers, which specifically the construction industry is facing. The nature of these barriers must be exposed in practice. To be able to optimize how resources are being managed, these barriers will have to be tackled. Given the literature, it should be possible to develop standardizations and create an information exchange between construction companies. A hypothesis for optimizing resource management between multiple urban construction projects is that implementing a centralized resource management system, such as a database or software application, can improve resource allocation and utilization. This centralized system could track the availability and location of resources, as well as allow for real-time communication and coordination between project teams. Additionally, implementing strategies for resource sharing and reuse, such as renting or borrowing resources from other projects or companies, may also help to optimize resource management. Through this research it is expected that a centralized system for urban construction projects, like the CLCT, can reduce the number of empty vehicle movements. To determine if this hypothesis is correct, it must be tested in practice. The following chapter will provide the framework to do so.

3. Research Framework

This chapter functions as the research framework. This chapter contains three sections. The first section addresses the chosen research design and its justification. Following the research design, the Unit of Analysis is introduced. Lastly, the research methods are addressed according to three different phases that are preserved throughout the research. Figure 6 visualizes the research framework in a flowchart.

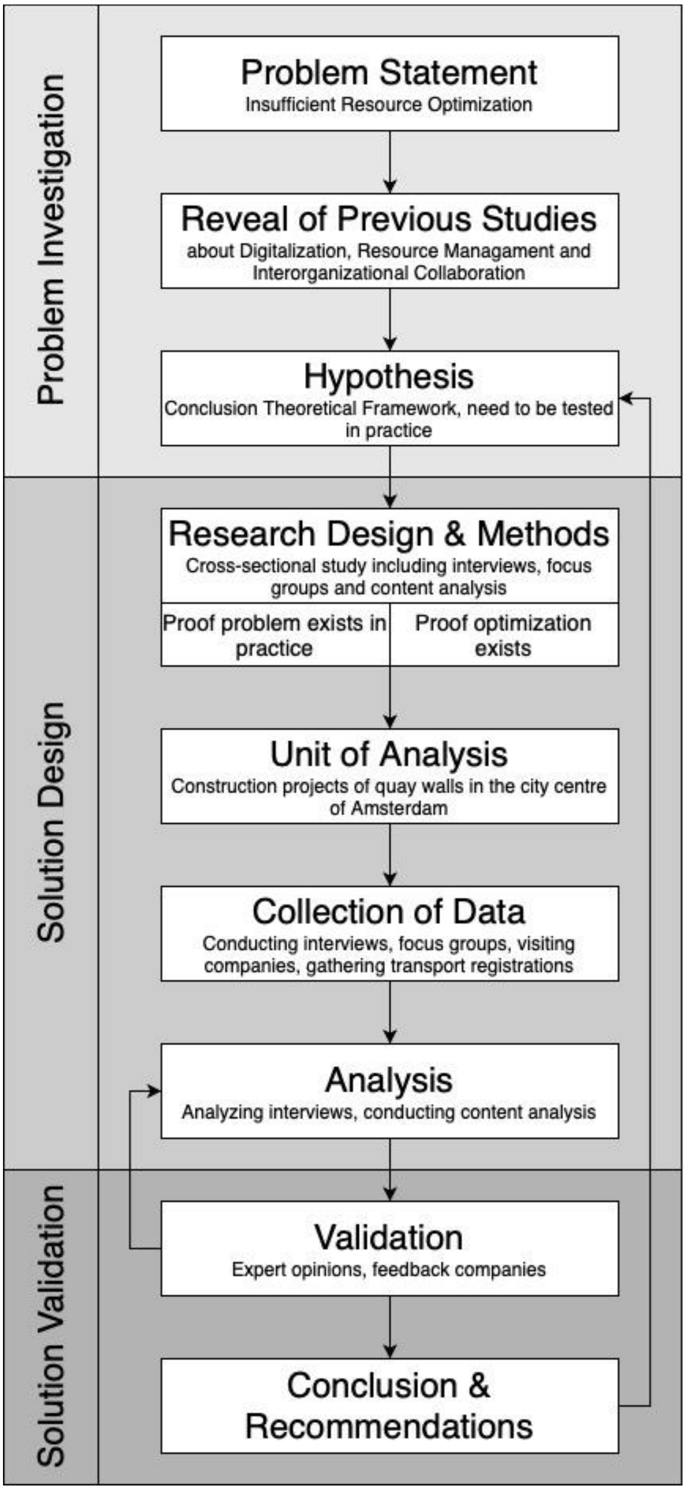

Figure 6. Visualization of the Research Framework (own illustration)

3.1. Research Design

According to Bryman (2012), a research design provides a framework for the collection and analysis of data. It provides the overall strategy to integrate the different components of a study in a coherent and logical manner. Ensuring that the research problem is addressed effectively. For the empirical part of this research, data is collected from construction projects of quay walls in Amsterdam. To do so, a case study design could be suitable. Case studies can consist of a single case, or multiple cases. This study entails multiple projects. The reason why multiple projects are required is to study the potential optimisation of construction logistics based on data connections between projects. However, the projects themselves are not the Unit of Analysis. The projects are part of a sample which is the Unit of Analysis. Bryman also prefers to describe this as a cross-sectional design, rather than a case study. Although it does have certain elements of a case study, since quay wall projects are rather characteristic for Amsterdam.

A Cross-Sectional Research Design is used to gather empirical data and to validate the system. It entails "*the collection of data on **more than one case** and at a **single point in time** in order to collect a body of **quantitative or quantifiable data** in connection with two or more variables, which are then examined to detect **patterns of association***" (Bryman, 2012).

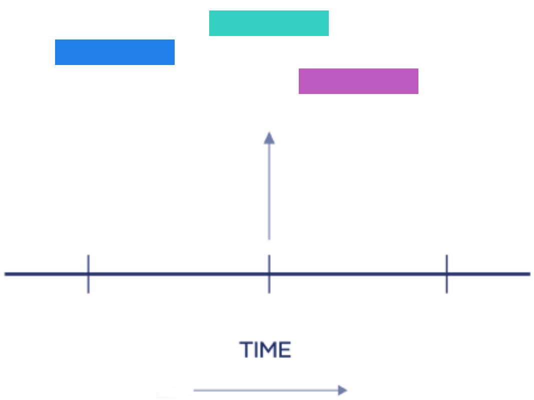

Figure 7. Collection of Data from three different points in time

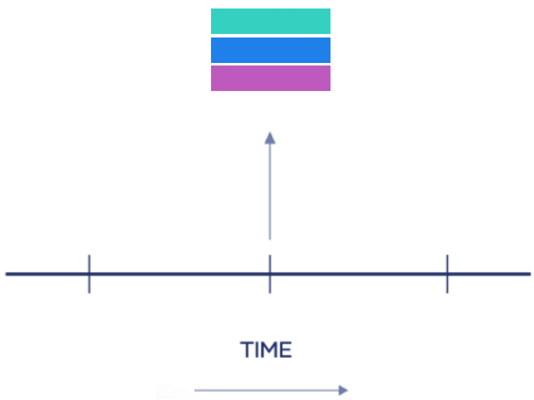

Figure 8. Cross-sectional Research Design (Thomas, 2020)

Three different samples of transport records of projects are used for the analysis. To enable the Cross-Sectional Research Design, these samples must take place at the same time. Therefore, the dates of transports are adjusted such that the project timelines are overlapping. Figure 7 displays the original visualisation of the three projects, while Figure 8 displays the adjusted visualisation that enables the Cross-Sectional Research Design.

3.2. Unit of Analysis

In this section the Unit of Analysis is described. It begins with a short introduction of research previously done in this field, which has been an inspiration for this research. This is followed with an introduction to the cross-sectional research design.

Research (de Bes, et al., 2018; van Rijn, 2020; van Merriënboer & Rondaij, 2020) shows substantial savings in time and money caused by applying new concepts in construction logistics. In the past few years, research has been done towards the development and implementation of a Cross Chain Control Centre (4C) specifically for the construction sector, also known as Construction Logistics Control Tower (CLCT). The aim of that research is 1) to provide insight into the reduction of operational logistics costs, and 2) to increase the sustainability of the logistics process. Throughout different phases of the research, several use cases in the Netherlands were considered.

Following up on these and finding an answer to the main research question[6], the Unit of Analysis considered is the 'Samenwerkingsovereenkomst Kademakers' (SOK). This agreement includes several construction projects in and around 'het Wallengebied' in the centre of Amsterdam. The municipality of Amsterdam is responsible for 1800 bridges and 600 kilometre of quay walls. A considerable amount is in bad condition and is situated in the historic centre. Many of them are over a hundred years old and where never designed for today's intensive use. Moreover, the maintenance policy has been reactive for decades, which has caused maintenance to be overdue. Due to the large and complex scope, the municipality of Amsterdam has entered into a long-term agreement with three parties to renew the quay walls in the city. These construction parties are Dura Vermeer, Beens Groep and H. van Steenwijk. Together they are responsible for the renewal of at least 300 meters of quay walls per year for the next six years.
Earlier research (van Rijn, 2020) achieved positive results in terms of the reduction of emissions caused by construction logistics over water. Thereafter, the municipality of Amsterdam stimulates logistics over water, back to the way it was hundred years ago. In the case of SOK, all the logistics towards and from the construction sites will be over water. The projects make use of electric vessels to transport equipment and materials. Some contractors have their own fleet of electric vessels, and some are working with a third party, in this case PK Waterbouw. And some contractors make use of consolidation centres. For example, Beens Groep is working with a consolidation centre in the port of Amsterdam.
Different urban construction projects are required for the cross-sectional research. To facilitate collaboration between different projects, the projects preferably would be constructed in each other's proximity, during the same period and sharing similar construction components. However, there is no insight into the city logistics and transports are not optimized yet because projects are carried out by different, typically smaller contractors. Thus, leaving room for optimization. The long-term collaboration and the repetitive work, makes the renovation of the quay walls in Amsterdam a suitable Unit of Analysis to investigate a new approach to reduce operational logistics costs and improve its sustainability. Moreover, conditions for collaboration are optimal. The projects are taking place throughout the centre of Amsterdam, multiple projects are constructed at the same time, they require mostly the same materials and equipment, and they use similar means of transportation.
Logistics data from projects is gathered through different contractors. Their transport movements are analysed to find similarities between transports that could have been bundled logistically. By proofing that indeed transports could have been bundled, the research demonstrates that there could have been a reduction in transport. Reduced transport equals reduced emissions, less nuisance, and lower costs. Currently, this cannot be achieved due to a lack of information sharing between projects. Following this knowledge, the research indicates which data is required to be shared, to facilitate this reduction.
Stakeholders in the CLCT project have expressed their desire to start small and expand while going. This is in line with the Minimum Viable Product (MVP) methodology. MVP is an important lean start-up technique that is focused on a quick, yet effective deployment of a product. It is a version of a new product which allows to collect feedback from the user with the least amount of effort. While still under development, a quick release provides early feedback from its users. Therefore, the product can be validated early in the development cycle. The product could then be iterated and improved before significant effort and investments are made. Furthermore, the limited availability of resources makes it difficult to carry out the full scope of the CLCT (see Table 1, p. 13). This methodology shines through in the approach towards a proof of concept.

[6] *How can resource management be optimized between multiple urban construction projects?*

3.3. Research Methods

A research method is a technique for the collection of data. The research methods for the application of the cross-sectional research design are elaborated in this paragraph. Typical methods for cross-sectional research are structured observation, content analysis, official statistics, and diaries. The aim of the cross-sectional research is to estimate how many transport movements could have been reduced in Amsterdam if transports where registered and information was shared appropriately. The research is subdivided into three subsequent phases. Each phase has its own purpose and methods to answer the corresponding research questions.

1. Problem Investigation

The first phase is the Problem Investigation. This phase entails an introduction to the topic where a frame of reference is created for the reader. It is followed with an in-depth problem analysis which is nourished by research on existing theories and reveals of previous literature. The Theoretical Framework is divided into three main topics of interest: digitalization, resource management, and interorganizational collaboration. It investigates the current level of digitalization in the construction industry and the current techniques of resource management. Besides it critically evaluates the existing published work on these themes and explores the state of the art of relevant technologies in the construction and logistics sector. The problem investigation is carried out to 1) better understand how resources are currently managed, 2) what technologies already exist but are not being implemented yet due to certain barriers 3) which resource information would be required digitally. The phase ends with a hypothesis which consist of a conclusion of the Theoretical Framework.

2. Solution Design

The second phase is the Solution Design. Here it is determined how the hypothesis can be tested in practice. A cross-sectional research design is applied here. The Solution Design consists of two parts. The first part is focused on proofing that the problem exists in practice. In other words, does the theory correspond with practice. More specifically with the practice in the Unit of Analysis. This part of the research is mainly covered by semi-structured interviews, company visits and focus groups. Moreover, knowledge has been gathered through meeting with participating companies, organizations, and educational institutes.
Afterward, a Requirements Analyses is carried out, comprising of the identification of the vague needs which are translated to requirements and specifications of the system. The requirements analysis is important because information is shared between different parties with different backgrounds, Company A might need different information on their resources than Company B. After the problem has been investigated, and the needs of the system are defined, deductions can be made to construct the system requirements. The system requirements define the scope of the system. To be able to design and test the system, real data is necessary.

The second part of the Solution Design consist of gathering logistics data from different projects in the Unit of Analysis. The data received consists of transport receipts, company statistics and diaries. A content analysis is carried out over the received data. This is an analysis of documents and texts that seeks to quantify content in terms of predetermined categories and in a systematic and replicable manner (Bryman, 2012). This data is transformed to a uniform set of samples. These samples contain logistics information of the construction projects of quay walls that have been constructed in and around the city centre of Amsterdam. This set of data is used for a minimalist discrete event simulation. This is a simulation method used to model the behaviour of a system consisting of discrete events occurring at specific times. Discrete event simulation can be used to predict the short- and long-term behaviour of a system, for example to determine how a production line will function under different conditions or to predict the long-term effects of changes in a system. Alternative methods to model and analyse systems are e.g., System Dynamics or a Monte Carlo Simulation. System Dynamics is more applicable to study the behaviour of complex systems, while a Monte Carlo Simulation uses statistical techniques that are particularly useful for estimating probabilities of different outcomes. The discrete event simulation is preferred in this case because the arrival dates (discrete events) of transports at the construction site is in the interest of the research. The discrete event simulation is carried out in a manual manner, examples of calculations are provided in Appendix E. Within the data sample, events are analysed and matches between transports are indicated. Interventions are then proposed which would result in an adjusted planning or routing of transports. The simulation keeps track of the effects that the proposed interventions are causing, by estimating the tonne-kilometres (tkm) that the intervention would save.

3. Solution Validation

The final phase is the Solution Validation. In this phase a verification and validation of the results is provided. Firstly, to verify whether the interventions have a genuine effect on the total distance of transports, the data is analysed, and the interventions are simulated over the transport records. To do so, the unit of measure 'tonne-kilometres' is introduced. Tonne-kilometres (tkm) is a unit of measure of freight transport which denotes the transport of one tonne of goods by a certain mode of transport over one kilometre. From the transport records an unused tkm value can be derived. This value quantifies the potential. In other words, a higher unused tkm value means that the transport was inefficient and that there is a high potential for optimization. The analysis aims to improve the efficiency of transports, such that there is less wasted fuel and less transport in the city. The unused tkm value can be reduced in two ways; 1) by decreasing the unused capacity, which will increase the load factor of the vehicle; or 2) by reducing the kilometres of the transport. Often decreasing one will increase the other. However, the right balance must be found.

The unused tkm of the transport records can be determined. Subsequently the unused tkm, after simulating the interventions must be determined. If the simulation results in a lower unused tkm value, the intervention has optimized the transport. In this fashion the impact of the interventions can be quantified and compared with one another.

This process is done in two stages. In the first stage, the interventions are simulated against the actual transport records. This displays what could be achieved within the actual planning on projects. In the second stage the effects of a Control Tower are simulated. This means that planned transports can be rescheduled within certain boundaries to optimize the overall logistics in a city. Where in the first stage the possibility to apply certain interventions did not exist, in the second stage this possibility could be created by the Control Tower simulation. The Control Tower can interfere with the schedule of the projects.

The second step involves the validation of the findings. It is essential to confirm whether the results align with the opinions of experts. To ensure the accuracy of the solution, several organizations involved are invited to participate in expert meetings. In these meetings the findings from the analysis are presented, together with the proposed interventions. Based on this information, their knowledge and expertise of project management, they are asked to review the interventions. After the validation process is completed, the next step is to incorporate the feedback received from the experts and make necessary revisions to the solution. Once the revisions have been made, the solution can be finalized, and conclusions can be drawn.

4. Conceptual Interventions

The focus of this chapter is Smart Urban Construction Logistics in which different feasible approaches are explored that the construction sector can implement. The aim is to present potential interventions that could be adopted by the construction industry to improve their logistics, and by doing so, minimize the environmental footprint. These interventions are designed to be practical and will provide valuable insight into how construction logistics can be improved in a smart and sustainable manner.

Resource logistics can be divided into two categories: stocks & corridors. Stocks are the inventories that are present on a specific location. In urban projects, space is typically scarce, so the amount of stock on the project site is limited. Work stock can be kept here, idle stock should be moved from the project site to free up space. Stock that is temporarily idle, but will be used the next days or weeks, can be stored in an Urban Stock Location (USL) within the city. Here small quantities of materials, equipment, and waste for (re)use in urban projects can be stored for a short period of time. Outside the city, a Consolidation Centre (CC or Hub) can be used to facilitate storage, bundling, and crossdocking larger amounts of resources. At this location, materials from suppliers, equipment from contractors, waste from projects, and workforce from outside the city are supplied and distributed all over the city by smaller vehicles. The corridors are the routes between stock locations. Within the urban area, smaller vehicles are being used to move stock between; 1) project and project, 2) project and USL, 3) project and CC, and 4) USL and CC. Figure 9 illustrates the stocks and corridors that exist in an urban area. Both stocks and corridors have certain restraints. Stock locations can be constrained by quantity, timing, and availability. Corridors by road capacity, timing, and restrictions. Together these constraints form a problem of supply and demand that must be managed efficiently.

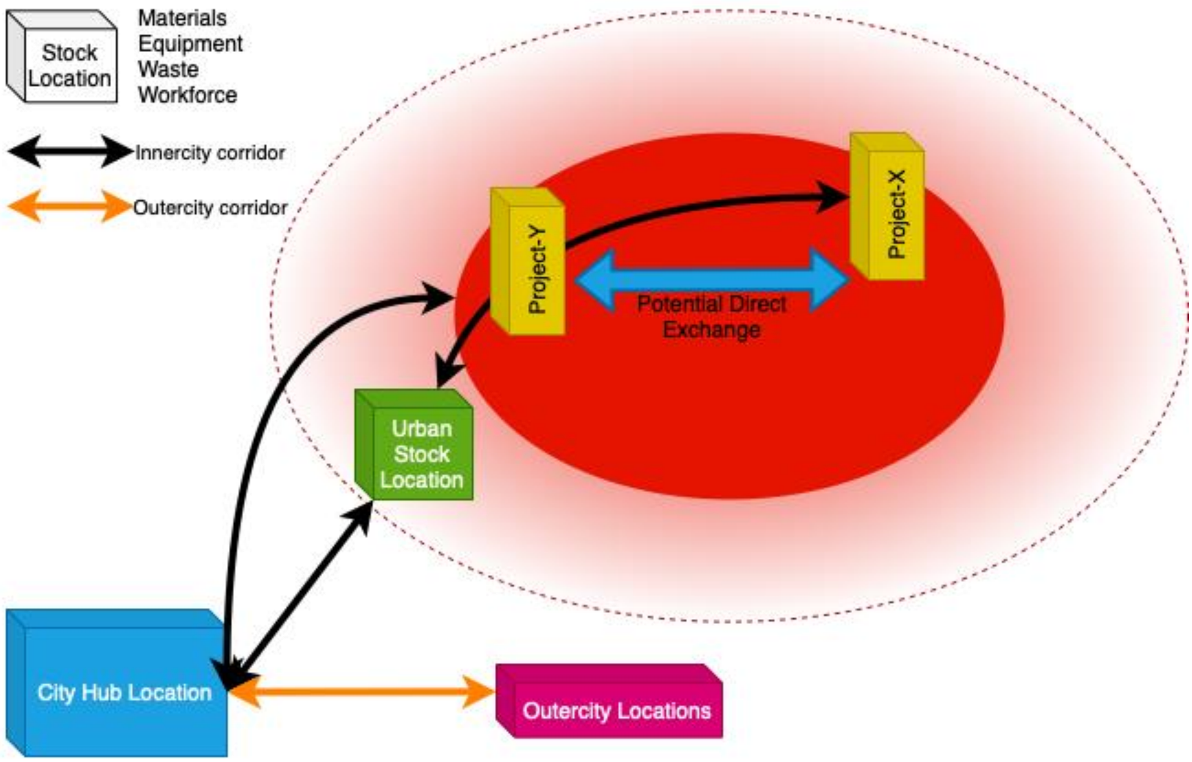

Figure 9. Diagram Stocks & Corridors in Smart Urban Construction Logistics

The following sections are dedicated to the conceptual interventions. These interventions contribute to the reduction of total travelled distance of vehicles. Below an overview of these interventions:

1. Shared import/export Corridor (material/waste)
2. Direct Exchange between Projects (reuse, circularity)
3. Urban Stock Location (buffer)
4. Cross docking (bundling inner city transports)

4.1. Shared Import/Export Corridor

An effective intervention to address the logistics of incoming and outgoing resources in the city centre is to implement shared logistics corridors. Often, several projects are simultaneously ongoing in the city centre, with separate logistics management. However, this can lead to a scenario where project X requires specific resources on the same day that project Y requires the same resources. To minimize the number of transportation movements and optimize resource utilization, shared logistics corridors can be established between the two projects.

This strategy would enable the resources to be shared between projects and transported together to the construction site, thus reducing the overall transportation and logistics costs. This approach can be further optimized by considering the movement of empty vehicles. In some cases, a construction project may require an empty vehicle for the disposal of materials or equipment. Instead of the vehicle returning empty, it could be loaded with materials or equipment from other projects in the city centre that require transportation. By doing so, the number of empty vehicles on the road can be reduced, and the overall load factor of transportation can be increased.

Typically, the delivery of materials and equipment to a construction site results in empty vehicles at the project site, which often return empty to their origin. By implementing shared logistics corridors, these empty vehicles can be utilized to transport materials and equipment to other construction projects in the city centre. This strategy can reduce the number of vehicles on the road, lower transportation costs, and promote sustainability by optimizing resource utilization.

In conclusion, the implementation of shared logistics corridors and the optimization of empty vehicle movements are effective interventions to address the incoming and outgoing logistics of construction projects in the city centre. By sharing transportation resources, the overall number of vehicles on the road can be reduced, transportation costs can be lowered, and sustainability can be promoted by optimizing resource utilization.

4.2. Direct Exchange between Projects

Gaining visibility into the inflow and outflow of materials for construction projects can encourage the reuse or repurposing of waste materials in surrounding projects, promoting a more circular economy. For instance, if a construction project, such as Project X, involves excavating soil, the quality of the soil can be evaluated, and if it meets the required standards, it could be repurposed in a nearby project that requires soil. This would eliminate the need for new soil to be transported to the site, thereby reducing transportation costs, and minimizing carbon emissions.

Similarly, other standard products such as pavement tiles could be reused or repurposed in neighbouring projects, reducing the amount of waste generated and promoting sustainability. By having access to information about the materials used in various construction projects, construction companies can optimize their resource management strategies, promoting a more efficient use of materials and reducing waste.

In summary, by incorporating insight into the inflow and outflow of materials in construction projects, companies can promote a more sustainable approach to construction. The repurposing or reuse of waste materials can reduce transportation costs, minimize carbon emissions, and foster a circular economy. Ultimately, this approach can lead to a more efficient and cost-effective use of resources, resulting in a positive impact on both the environment and the construction industry.

4.3. Urban Stock Location

An additional intervention that can enhance Smart Urban Construction Logistics is the implementation of an Urban Stock Location (USL), where construction materials and equipment can be stored for a short duration, typically ranging from a few days to a few weeks. By utilizing a USL, construction companies can avoid transporting materials and equipment outside of the city, which would otherwise require longer travel distances and result in higher transportation costs and carbon emissions.

With a USL in place, materials and equipment can be delivered to the site as needed, thereby reducing the need for long-term storage on the construction site itself. This can help optimize the use of space in urban areas and mitigate issues such as congestion and noise pollution. Additionally, by having a shared USL located within the city, construction companies can benefit from a more streamlined logistics process and reduced transportation costs, which can ultimately lead to higher profits.

Overall, the USL intervention is an effective way to improve the efficiency and sustainability of construction logistics in urban areas, by reducing transportation distances, minimizing congestion, and optimizing the use of space.

4.4. Cross Docking (Hub or CC)

Cross docking is a logistics process that involves transporting goods directly from the supplier to the client without any intermediate handling or storage by a third party. The process takes place at a distribution docking terminal, which could be a hub or consolidation centre. This strategy is efficient in reducing the time and cost of the transportation process, and it minimizes the need for storage space and handling equipment.

In the context of Smart Urban Construction Logistics, cross docking can be combined with the Urban Stock Location intervention to optimize the delivery and storage of goods. The Urban Stock Location could be used as the primary destination for the delivery and storage of construction materials, and the cross-docking process can be integrated to ensure that the goods are transported directly from the supplier to the Urban Stock Location, without any intermediate storage or handling. This integrated approach can reduce transportation costs, minimize congestion and emissions, and optimize the use of space in urban areas. Moreover, it can help to streamline the construction logistics process and enhance the overall efficiency and sustainability of the construction industry.

5. Requirements

To fully grasp the needs of a centralised management system, hereafter referred to as 'the system', it is essential to conduct a requirements analysis. This chapter aims to do just that, offering a breakdown of the necessary features and functions. While it is necessary for the reader to understand how the requirements were developed, it should be noted that the development of the final system falls outside the scope of this research. A basic understanding will however contribute to laying a strong foundation for further learning and mastery of the subject.

A hierarchy is followed to establish the requirements of the system. At the top it starts with high level of abstractions, going down to a more detailed level. This chapter follows the same hierarchy as Figure 10 displays. From an abstract point of view, the business requirements are determined in section 5.1. These requirements describe the purpose of the project. Subsequently, in section 5.2 a closer look is given at what the users of the system need. Focus groups, expert opinions and interviews are the source of these needs. Hereafter, in section 5.3 these requirements can be translated to a more detailed level, the system requirements. The last section contains the conclusion of this analysis.

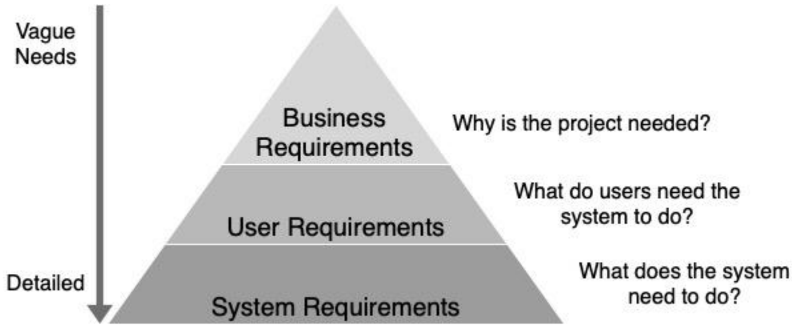

Figure 10. Requirements Hierarchy (own illustration)

5.1. Business Requirements

The business requirements are the highest level of abstraction. Here the purpose of the project is determined, asking 'why is this project needed?'. This includes elevated statements of the goals, objectives and needs of the organization. There are multiple organizations involved in construction projects (e.g., contractors, suppliers, logistics services and the municipality). For this research, SOK is considered the organization of interest. SOK consists of several contractors that share in essence the same ambitions and goals, while the municipality of Amsterdam defined criteria that must be demonstrated in this contract.

From the literature it can be concluded that the construction industry is a slow adopter in terms of digitalization, which is causing the problem of insufficient optimization in resource management in urban areas. As a result, the construction sector has a high contribution to the amount of traffic in urban areas. Traffic which is causing nuisance and pollution to the environment. Therefore, a goal of the Municipality of Amsterdam is to reduce traffic caused by the construction industry. For the contractors it would be reducing logistic operation cost and reducing its carbon footprint. Optimizing resource management of urban construction projects is one of the possible solutions. The business requirements are describing the purpose of a project. In general, the purpose is to reduce the effects, by solving the problem. This translates to reducing the amount of traffic caused by the construction sector, by optimizing resource management between multiple urban construction projects. The project can be acknowledged as a success when the purpose has been accomplished, while meeting the requirements. Demonstrating the potential reduction of traffic is therefore essential but should not be the only measurement. When a certain implementation would be too costly, it will be questionable whether it is something to invest time and money in.

Following earlier research (de Bes, et al., 2018), a vision for the CLCT has been established after extensive consultation with stakeholders in construction logistics practice on all levels. The CLCT will form an instrument for tactical and operational planning, operational control and monitoring, and supervision of the construction logistics process of one or more construction projects in a region. From the Kick-off meeting held to discuss the direction in which the CLCT project is heading, it has been concluded that the stakeholders would like to see a quick and easy set-up for the CLCT. Additionally, for the scope of this research, the vision would be too large to be realized in the limited amount of time available. A smaller vision that requires less time is therefore necessary. Taking these points into consideration, a Minimal Viable Product (MVP) is a suitable method that requires less time yet contributes to the development of the vision for the CLCT. Some functions of the CLCT can already be created and tested. Gradually these functions can be expanded into the complete vision of the CLCT.

Part of the business requirements can be derived from the stakeholders. A network analysis is therefore an essential segment to be discussed. Previous research (Tesselaar, 2020) also focussed on the design of the CLCT. The research analysed a general set of actors that would typically exist in a construction project. The main take away from this analysis is that there are four key players in construction logistics: contractor, supplier, logistical service provider and municipality. This group of actors is also considered in the case study (see Table 3).

Table 3. Overview Stakeholders SOK

Stakeholder	Case SOK	Interest
Client	Municipality of Amsterdam	Improving Air Quality
Contractors	Dura Vermeer, Beens Groep, H. van Steenwijk	Reducing Logistics Costs and Increasing Revenue
IT administrators	TiQiT	Increasing Revenue
Logistics services	PK Waterbouw	Increasing Revenue
Suppliers	-	Increasing Revenue

5.2. User Requirements

The previous section defined the business requirements, where the purpose of the project has been described. This section takes the perspective of the users of the system into consideration and outlines what the system must be capable of doing for the users. Primarily, a description of the user is necessary. An essential part of the purpose is the management of multiple urban construction projects. This means that there are multiple users of the system. Using the system in different ways. The contractor will mainly be uploading data and reading new insights. The main user of the system is assumed to be the contractor. To understand how resources are currently managed by the contractor, semi-structured interviews were carried out.

Two SOK contractors have been interviewed, Beens Groep and H. van Steenwijk. From the interviews it can be determined that currently both companies do not have any specific software in place to facilitate supply chain management. In general, activities are communicated by means of email, calls, or text messages. However, both companies keep track of their daily

activities. Beens Groep keeps track of the transportation of materials over water, their workforce, and the use of equipment. The logistics data is gathered manually in Excel sheets.
At H. van Steenwijk there are no Excel sheets, but paperwork that contains handwritten information. A reason for that is that the company never felt the need to do this digitally due to the relatively small project size. The contractors mentioned that with the CLCT they aim to improve operational efficiency and to efficiently use equipment. To do so, they would like to have more insight in the logistics in the city.
For the carrier the situation is somehow different. In this case, PK waterbouw has been interviewed. From the interview there are a few take aways. Firstly, the carrier does not know into detail when and which material will be moved until one or two weeks in advance. However, for each project a rough estimate is made about how many ships must be reserved in a certain period. Also, if a delay in the planning (week or day level) of the contractor occurs, it will be either communicated by phone or email, or digitally with an experimental system called TiQiT. Secondly, there is a certain level of digitalization, which makes is possible to localize its fleet. Also, mainly Excel is used as an information system, but they are experimenting with TiQiT to improve this. Automated processes are currently a bridge too far according to the carrier, this would require many dependencies between activities. Decisions must be made manually, so having a clear overview is preferable. Moreover, the carrier does not see transport bundling of multiple projects a realistic possibility. An example is provided of two contractors, who both did not want to risk any possible disruptions in their planning caused by transport bundling. Though, it is questionable to what extent the carrier already does bundling itself, it could be part of its revenue model.
As mentioned by the carrier, an experimental system is being used. Also, a short interview has been held with the IT administrator of this system. Here the main take away, but rather contradicting the literature, is that software is not the limiting factor. In IT many things are possible because it is rather easy. The IT administrator does not see any added value in the use of BIM. He calls it rather expensive and too complex to use. Instead, he suggests ERP and mentions that, compared to Excel, you cannot break the system by moving cells or columns. Moreover, it is essential to have reliable data, connecting systems is not the difficult part.

In the context of MVP, considering different types of stakeholders does not fit the method because it would involve an additional set of requirements. Hence, the user of the system is for the purpose of this research limited to a single group, the contractors. Also, with the idea that if this succeeds, the contractor will have the insight to make better decisions and communicate with their supply chain partners. Now that there is more insight in how the stakeholders are working together in the supply chain, deductions can be made, and user requirements can be determined. These are determined by using a prioritization hierarchy. Following this prioritization, the most important requirements can be defined. This method is in line with the approach to develop an MVP, since focus should be on the most important requirements.

Contractors have mentioned that it would be valuable for them to have more information easily accessible to be able to optimize their operational efficiency. One way to optimize their efficiency, is to reduce the number of transports needed. Transports could be bundled together with other projects. For that to happen, insight in transports of surrounding projects is required to visualize where and how it can be optimized. Contractors would like to know how much capacity is planned and how much is unused. This could be defined in terms of weight or volume. Moreover, they like to know if there are other transport corridors of other projects nearby that could be a possible bundling partner. Also, it is relevant to know which material or equipment is being transported. Maybe the same material/equipment is needed on another location. Consequently, another requirement is the insight in availability of resources. If a certain equipment is already present in the city, new equipment does not need to be transported from outside the city. Also registering material and waste would predict the required transports.

The next step would be implementing restrictions in the area. Transports could be bundled together in a bigger vessel, but if this vessel does not fit through the corridors, the transport is not possible. Nevertheless, without these requirements the solution is still viable. Contractors would have to continue planning routes as they are currently doing. In a further developed stage this could be optimized.

Another interesting step would be to add emission calculations. Currently contractors must report their emissions which takes additional time due to calculations. Automatically predicting and tracking emissions within construction logistics would be suitable with the system. Also providing automatic bundling suggestions, such that the contractor does not have to investigate the data for suitable matches.

Integration with BIM is something the stakeholders are wishing for but will be too complex to facilitate within a single thesis research. The integration with BIM requires a lot of work, and as mentioned by the IT administrator, BIM is quite expensive and smaller contractors do not use it. Therefore, integrating with BIM does not meet the business requirements for this research. However, it is interesting for future research, and it should be considered that the system should be ready to be used with BIM. In Table 4 the prioritization has been applied and the requirements summarized.

Table 4. Prioritization of User Requirements

1. Insight in transports of surrounding projects:
    a. Weight/Volume of transport
    b. Vehicle Dimensions
    c. Load factor of transport
    d. Resources which are transported
    e. Origin and destination of transport
2. Insight in resource availability:
    a. Equipment
    b. Material
    c. Waste
    d. Personnel
3. Route planning based on:
    a. Travel time
    b. Road capacity/intensity
    c. Passage profiles
    d. Bridge heights
4. Estimating emissions
5. Automatic bundling suggestions
6. Integration with BIM

From the Kick-off meeting and the interviews with contractors and municipality, it can be concluded that currently there is a need to make the first step into creating a CLCT. Gathering data to feed the centralised management system is part of that first approach. Following the prioritization, the most important user requirements can be derived. Starting with a system that meets these user requirements gives the opportunity to receive early feedback and create a strong data foundation. At a later stage, additional requirements can be extended.

5.3. System Requirements

In this chapter the user requirements are translated to system requirements. These requirements explain what the system must do to meet the user requirements. They can be subdivided into functional and non-functional requirements. The functional requirements are describing the required operation of a system, a behaviour to be performed by a system function. Non-functional requirements describe the way in which the system must provide this operation. Examples are provided in Figure 11.

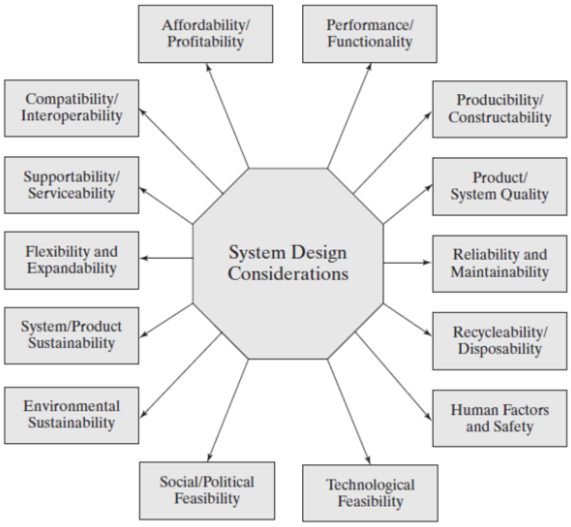

Figure 11. System Design Considerations (Lecture notes TU Delft, System Engineering Management)

The system to be designed must meet the business and user requirements. The functional requirements follow the prioritization. To ensure that the user can get insight in the upcoming transport needs, it is necessary for the users to share their upcoming transport needs with the system, so other users can have access to this data. The same accounts for the availability of resources. By sharing the availability, other users can respond to supply and demand. The retrieved data can be transformed into overviews and can create new insights. Requirements to be considered for the design of a centralised resource management system are displayed in Table 5 and Table 6.

Table 5. Functional Requirements

No.	Functional Requirement
1.	The system must allow the user to share (upload or sync) data
2.	The system must make relevant data from other users visible / ensure that the user gains (partial) insight into the data from other users
3.	The system must gather, process, and visualise information in such a way that it generates new insights for all users

Table 6. Non-Functional Requirements

No.	Non-Functional Requirement
1.	Affordability
2.	Compatibility
3.	Serviceability
4.	Feasibility
5.	Reliability
6.	Functionality

6. Analysis Procedure

In this chapter the execution for the analysis of the data samples is presented. The analysis is focussed on getting insight in material flows, finding the potential for resource optimization, and indicating where interventions would have been possible by applying the discrete event simulation. In the first section the three case studies used in the Unit of Analysis are summarised. In Section 6.2 the execution for the analysis of the transport records from the different construction projects is elaborated. This analysis contributes to finding the critical logistics resources that should be managed collectively. Subsequently, in Section 6.3 the approach for the analysis on the interventions is provided. This analysis determines if the interventions could be applied based on the Unit of Analysis. Lastly, for verification each intervention is checked if it meets the requirement of reducing the number of empty vehicle kilometres.

6.1. Case Descriptions

In the Unit of Analysis there are three cases analysed. The project names are Gillis, Singel and Herengracht. The original intention was to examine three quay wall projects carried out by contractors who are part of the SOK agreement, with the anticipation that sharing information would be more straightforward amongst these parties. However, due to constraints in accessing data from various contractors, this plan became unfeasible. As a result, alternative projects involving civil works in the centre of Amsterdam were evaluated and selected for the Unit of Analysis. They are briefly outlined in this section.

6.1.1. Singel

The Singel project is situated in the heart of Amsterdam, adjacent to the canal of the same name. The project was initiated due to the subsidence of quay walls, which posed a safety risk and required immediate attention. To address this issue, the contractor developed a temporary emergency solution involving a sheet pile construction installed alongside the quay wall. The new structure provided the necessary support to reinforce the quay walls and ensure stability. To complete the project, the subcontractor, Rutte Groep, needed to fill the gap between the emergency sheet pile wall and the old quay wall with sand (see Figure 12). To transport the required materials, the contractor utilized barges that could carry up to 80 tonnes of sand.

Figure 12. Temporary emergency measurement (Gemeente Amsterdam)

6.1.2. Herengracht

The Herengracht project, located nearby the Singel project, is also facing issues with the subsiding quay wall. The project underwent a complete renovation to address this issue. The first step was to demolish the old quay wall between the new sheet piles and the water. Next, new steel piles were drilled into the ground and filled with concrete to form the foundation for the new quay wall. Large prefabricated concrete walls were then installed on top of the piles to complete the structure. After the new quay wall was constructed, the space behind it was filled with sand, and the front of the quay was finished with masonry. The result is a strengthened and revitalized quay wall that is expected to last for many years.
To ensure the project was completed efficiently, the contractor, Beens Groep, maintained a weekly report documenting the daily activities. This report included information on the transportation of materials via barges. Depending on the volume of materials required, the contractor utilized two different types of barges, capable of carrying 40 or 78 tonnes. The contractor also utilized a hub located in the port of Amsterdam for transporting materials to and from the project site. These transportation activities were documented and used for this analysis.

6.1.3. Gillis

Project Gillis is the final project included in the Unit of Analysis. It focused on the redesign of Gillis van Ledenberchstraat, which is located in the vicinity of the city centre of Amsterdam. One notable difference between this project and the previous ones is that the contractor, Van Wijk, used a tipper truck for its material transport needs, as opposed to barges. The project's proximity to a canal, however, provided an opportunity for interventions that could potentially improve the logistics. The resources for this project were primarily sourced from suppliers in the port of Amsterdam. In addition, the municipality of Amsterdam's materials office provided standardized materials, such as street gullies, which are required to be used in the city. This ensured that the project met the necessary standards and requirements set forth by the city.

6.1.4. Data Gathering

To create a centralized system for analysing and simulating transport records, data from various projects must be integrated into a uniform database. However, each project uses a different method for recording data, including delivery notes, diaries, and weekly reports. These records include information such as the Project Name, Date of Transport, Origin and Destination, Material, Weight of Material, and Vehicle characteristics.

6.2. Finding the Potential

This section presents the execution for the first analysis which is focussed on discovering the potential for resource optimization in construction logistics. Finding this potential provides guidance into the subsequent analyses. There are two topics being analysed which will expose the potential. These are the material type which is being transported and the load factor of transports. In other words, the analysis reveals what is being transported and how efficient.

The sample which is analysed contains transport records of the three construction projects from different contractors, over a timespan of approximately three months. The materials which have been transported are grouped into larger categories to get a better understanding of the material flows. Besides, from the data it is determined whether the destination of the transport is located in- or outside the city centre. In case it is an outgoing transport, a distinction is made between 'non-reusable' and 'potentially reusable' resources.
Furthermore, an important indicator of efficiency in logistics is the load factor. The load factor is the ratio of the average load to the total vehicle freight capacity. In other terms it is the

utilization of the available capacity. In the case study, the load of each transport has been recorded as well as the maximum capacity of the used vehicle. With these numbers a load factor is calculated. A distinction is made between ingoing and outgoing transports. The load factors have been categorized in groups. An empty vehicle has a load factor of 0% and a vehicle carrying the maximum capacity has a load factor of 100%. Load factors that are larger than 60% are assumed difficult to improve. The potential improvements are therefore considered to be in the domain below 60%.

6.3. Simulation Process

To ensure accurate analysis and simulation, the different sources of information need to be converted into a single format. This will allow for further calculations, such as determining the travelled distance of the transport, the load factor, and the unused tonne-kilometres (tkm). A high value for unused tkm indicates low transport efficiency, while a fully loaded vehicle has no unused tkm and is considered to be operating at maximum efficiency. The unused tkm is calculated as follows:

Equation 1. $$unused\ tkm = (\max load - material\ weight) * distance$$

The unused tkm is calculated for each transport record with a load factor below 60% since a higher load factor is deemed sufficient and difficult to further optimize. The next step is to engage in logical thinking. Interventions are carefully recorded based on their practical feasibility. In this context, it is important to note that each transport record may have one or more possible interventions, or it may not have any viable interventions at all. In case multiple interventions are possible, the interventions which generates the lowest unused tkm value will be selected since it is the most efficient optimisation. Interventions considered are:

1. Shared Import/Export Corridor
2. Direct Exchange
3. Urban Stock Location (USL)
4. Cross docking (CHL)

For intervention 3, a feasible location has been assumed based on communications that involved the municipality of Amsterdam. The Urban Stock location is assumed to be in the Oude Haven of Amsterdam. For intervention 4 the assumption is made that the current hub location of Beens can be used for cross docking purposes of other companies (see Figure 13).

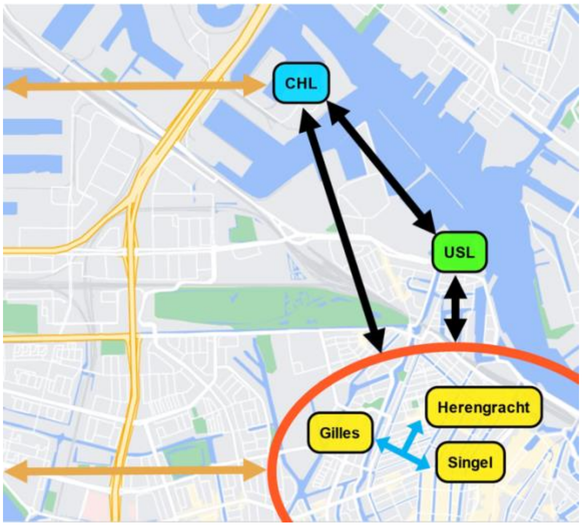

Figure 13. Project, Urban Stock and Hub locations mapped out.

After analyzing individual transport records in the first step, the second step considers the transport record database as a whole. Specifically, it seeks another transport record with an inefficient load factor based on the transport date. If no such record is found, it means that the intervention is still theoretically possible, but there was no viable solution based on the transport record database. However, if a match is found, the intervention can be applied, and a new unused tkm value can be calculated. If this new value is lower than the original value, it means that unused tkm has been saved, and the transport has been optimized. Appendix E provides some example calculations. It is worth noting that multiple interventions can be possible, but the one with the most saved unused tkm value is selected for the same reason.

7. Results

This chapter presents the findings of the analysis conducted in response to the research questions. The chapter is organized into several sections, beginning with an elaboration of the results from the analysis in Chapter 6. The material flows of urban projects were analysed to identify critical logistics resources, while the load factor of vehicles was used to identify areas of improvement. Next, the results from applying interventions to the transport records are presented. The interventions were evaluated based on their effectiveness in improving the logistics of the urban projects. The research findings are then presented, organized by the sub-questions of this research. Each sub-question is addressed individually. The results of the analysis and evaluation of the interventions are synthesized to provide a clear and concise answer to the main research question.

7.1. Material Flow

The data from the transport records has been gathered into a unified format, providing the opportunity for a data analysis. The materials have been categorised into larger groups, creating a general overview of the material streams within the projects. A visualisation of the transport flows is displayed in Figure 14. The number displayed behind each category represent the percentage of the total transports of all projects in the Unit of Analysis.

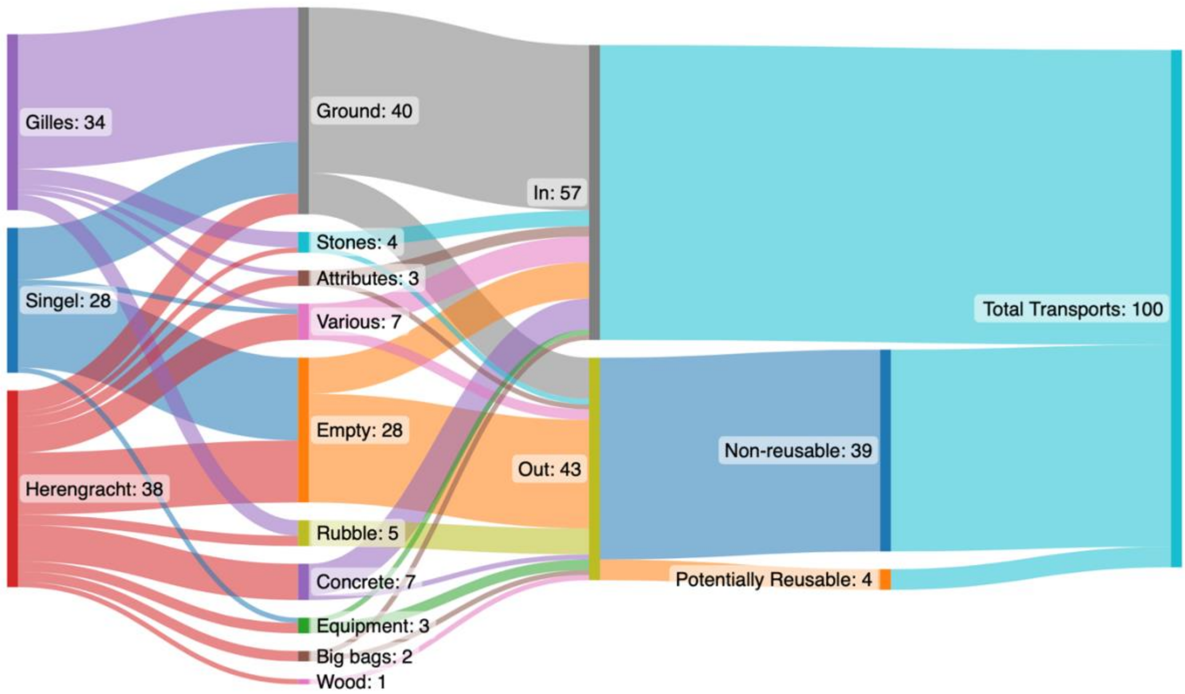

Figure 14. Sankey Diagram of Transport Records (numbers in %)

From the overview in Figure 14 it can be observed that a reasonable number of transports are categorised as ground (40%). The ground consists mainly of bedding soil, street sand, bottom sand, and contaminated soil. Most of it is destined to be used in projects. A smaller amount is being exported, mainly contaminated soil. It should be noted that the containers with contaminated soil cannot be used for other means without cleaning them beforehand. From all categories, ground has the highest average load factor (88%). A high load factor indicates that the efficiency of transports is relatively high and therefore potential for optimization relatively low.

Another interesting, yet not unexpected result, is the high number of empty transports (28%). The empty transports are mainly caused by the fact that vehicles return empty. This is however how they are registered from the perspective of the project. In case the logistics are carried out by a third party, this party aims to optimize their profits as much as possible. The logistics service supplier mentioned in a meeting that they almost never have empty transports. A smaller number of empty vehicles is intended to export goods from the project site, typically rubble, pavement stones or equipment.

7.2. Load Factor

The load factor can be described as the utilization of the available capacity. A higher load factor indicates a more efficient use of available capacity. From the transport records, the load factor can be determined. There are a few key observations to be found when considering the load factor of vehicles. Most noticeable is the outgoing empty transports (Load Factor = 0%). Nearly half of the outgoing transports are registered as empty transports (see Figure 16). This indicates a significant potential for optimization. The second largest group is transports with a load factor below 60%. Also here there is still room for optimization. Considering the ingoing transports (see Figure 15), the load factor indicates that most vehicles are loaded efficiently. 41% is considered as full load and another 36% of the transport has a load factor above 60%. Nonetheless, 12% of the vehicles is still empty, and another 11% is below 60% load capacity. To improve the efficiency, the focus should be on reducing these inefficient transports.

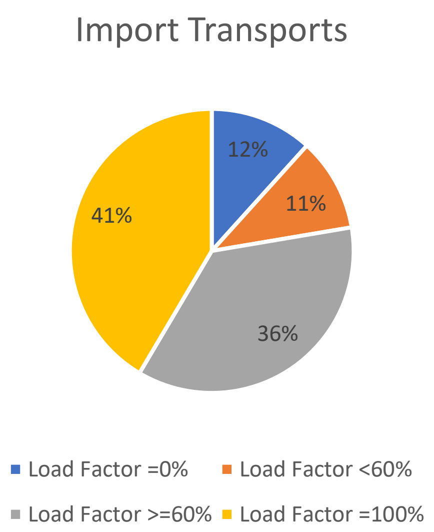

Figure 15. Distribution of Load Factors for Ingoing Transports

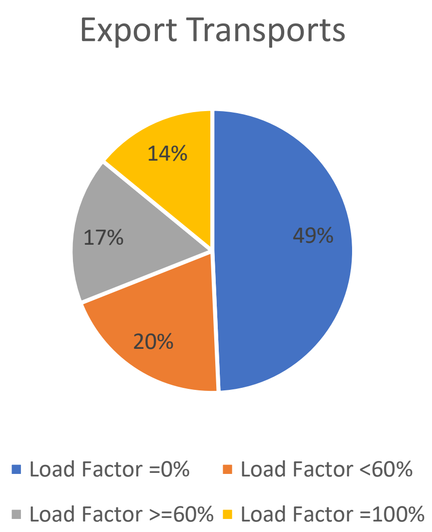

Figure 16. Distribution of Load Factors of Outgoing Transports

In Figure 17 it is displayed in which categories these inefficient transports are taking place. The graph shows that the vehicles transporting ‘Ground’ have been quite efficient, as well as ‘Big Bags’ and ‘Rubble’. These are typically bulk transports. The categories with a lower load factor, and therefore being less efficient are ‘Equipment’, ‘Stones’, ‘Wood’ and ‘Various’. These are typically smaller items or components that don’t fill a complete vehicle. Various items are transports holding two or more goods combined in a single transport. Equipment is an exception in this case. Equipment is required in certain moments and should not be kept idle for long. For stones it is also noticeably lower. It seems that the load factor is kept lower on purpose when analysing the transport records. An example can be found in the records were four transports where used, while three transports could have been sufficient (Project Gillis – Hydr. Menggranulaat).

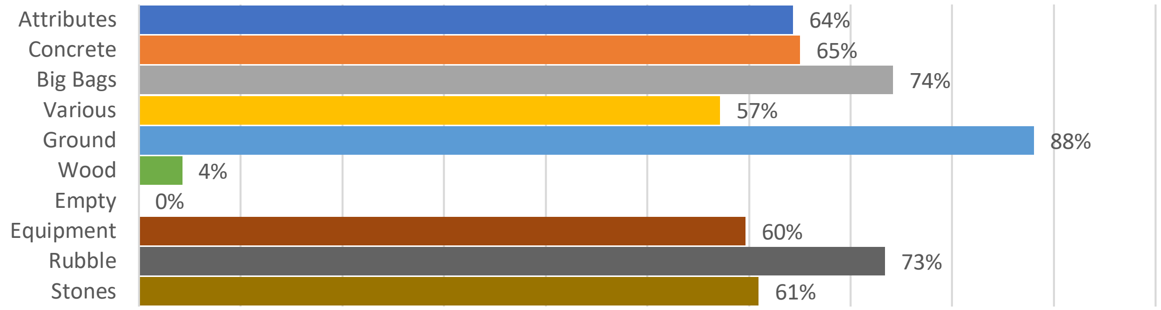

Figure 17. Load Factor per Category

The analysis exposes a significant obstacle in optimizing resource management among various urban construction projects, which is the uneven distribution of material flows. This often results in empty transports and inefficient use of resources. The root cause of this problem lies in the unequal supply and demand of materials across various construction projects. The currently used data is unable to completely solve this issue, as the projects are in similar construction phases and require similar materials. For example, if multiple projects are in different construction phases, like the demolishing phase, there may be a higher demand for export transport to dispose of waste materials. This could contribute to decreasing the imbalanced flow of materials and reducing empty transports. The unequal supply and demand of materials also creates a challenge for contractors, as they need to predict and plan demand of materials for each project. This can lead to overstocking or stockouts of materials, resulting in additional costs and delays.

To address this issue, it is crucial to establish effective communication and collaboration between contractors, to enable them to share information about the availability of materials and resources. This can help to reduce the imbalance of material flows and increase the efficiency of resource management.

In addition, implementing a centralized system that provides access to standardized logistics information, could also help to address this issue. By tracking the incoming and outgoing flow of materials across different construction projects, the system can identify potential imbalances and provide recommendations for resource allocation. Overall, addressing the imbalanced flow of materials and resources is crucial for optimizing resource management between multiple urban construction projects. By improving collaboration and implementing effective data management systems, contractors can minimize the inefficiencies and reduce costs associated with empty transports and unequal supply and demand of materials.

7.3. Applying Interventions

Chapter 4 introduced conceptual interventions that could potentially improve resource management in urban construction projects. To evaluate the effectiveness of these interventions, transport records were analysed. The results showed that while there is potential for application of interventions for both imported and exported goods, the potential is larger for exported goods (see Figure 19). For imported goods (see Figure 18), there is a smaller potential for intervention, with only 12% of all import transports deemed suitable for one or more interventions. However, it is worth noting that more than half of these transports still show the possibility for intervention, indicating that there is room for improvement even in cases where the potential is limited.

On the other hand, for exported goods, the potential for intervention is much larger, mainly due to the high number of empty transports that return from project sites. However, the transport

records also show that there are fewer possibilities for interventions when it comes to exported goods. This is primarily because there are no other transports exporting goods around the same time, making it challenging to apply the interventions effectively. As mentioned in the previous section, the imbalance in material flows has its effects here.
The transportation records emphasize the significance of identifying prospects for intervention in resource management. Although the potential for intervention may be restricted, the findings reveal that even minor enhancements can have a substantial effect in optimizing the utilization of resources in urban construction projects.

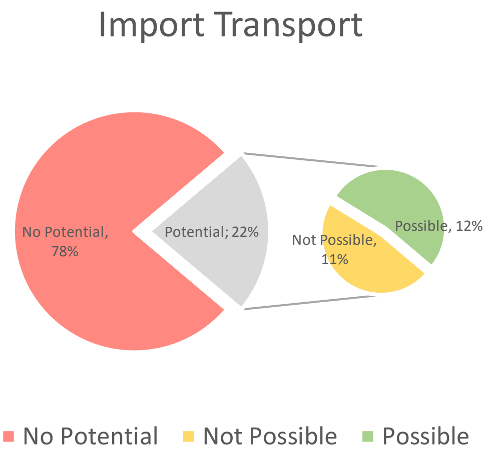

Figure 18. Distribution Ingoing Transports

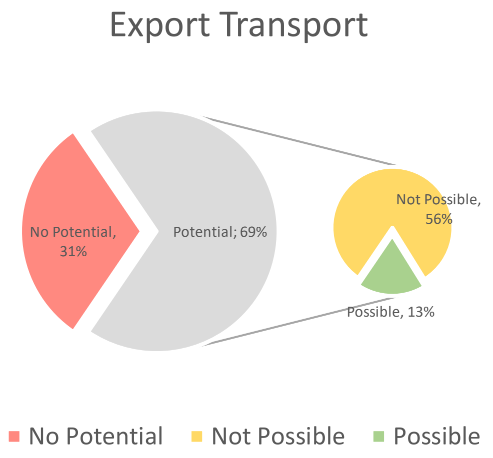

Figure 19. Distribution Outgoing Transports

7.4. Research Findings

The following section presents the research findings by providing answers to the research questions. Each paragraph is structured similarly, addressing a specific research question, and presenting its corresponding answer. Through this approach, the section aims to provide a clear and organized summary of the research findings.

RQ 1. How are contactors currently managing resources?
Previous literature revealed that there are currently plenty of new digital advancements in the construction industry, but the industry is a slow adopter to them due to the characteristic nature of construction projects. The contractors interviewed for this research cannot be generalised to the whole industry, but they are a good representation of what is happening on a smaller scale. These contractors are typically involved in small to medium sized infrastructural projects. The interviews exposed a less advanced approach towards digitalisation. There is no specific software used for logistic planning other than planning tools like MS Project or Primavera. Also, 3D models are not being used. It is mentioned that for these type of infrastructure projects there is no added value in using them. The work is typically visualised in 2D phasing drawings, which would suffice. Another barrier added by project management is that communication between contractor and third parties like suppliers or logistics services is typically done through phone calls. When communicating through calls, the possibility to store and exchange data is lost and must be found through other means. The perceived longstanding management approach is endorsed by the request for logistics data of recent projects. There is no standard in keeping track of transport records of projects. From each contractor I received a different composition of documents that contained logistics information. In the worst case it would contain numerous scanned documents that contained handwritten information, difficult to read and time-consuming to create a digitalised version. At best, the information was recorded through weekly reports in a spreadsheet. Yet still, data was quite rough and not specific enough.

Moreover, none of the contractors mentioned that they are currently applying optimizations, other than logical thinking.
To conclude, the experience gained from the interviews, meetings, and gathering of the data, agrees with the written literature about digitalisation in the construction industry. In smaller scale projects, the need to use digital tools is less prevalent. Besides, contractors of this scale typically do not have the financial resources to be able to operate with more advanced tools. However, the level of digitalisation at this stage seems to be lacking behind other industries. The digital tools contractors are currently using are not the advanced technology of which recent literature is currently writing about. Clearly this group of contractors cannot be generalised for the whole industry. It does however demonstrate that what is currently possible is not happening in practice, not at this scale.

RQ 2. What are critical logistics resources of urban (infra) projects that should be managed collectively?
Within the construction industry there is a lack of optimization in resource management. This has several reasons displayed in the Theoretical Framework and confirmed by the research done. To summarize there is a lack of standardization due to the fragmented nature of different stakeholders involved. This makes it challenging to implement standard practices, or protocols for resource management. Besides, projects are typically short-term, driven by financial goals, which causes a lack of focus towards long-term resource strategies. Mentioned in the previous paragraph, there is limited technology advancement at smaller sized companies that typically work at multiple reconstruction projects throughout the city. Small contractors are not using new computer systems and data is typically not recorded digitally. This is a crucial part required for the optimization of resource management. The construction projects lack adequate data and information on resource usage, making it difficult to identify where inefficiencies are taking place and where to apply measures of improvements. Finally, limited collaboration between construction parties. Typically, multiple stakeholders are involved in a project, making it difficult to coordinate resource management efforts across different teams and organizations.
Considering that collaboration could be a key solution to improving resource management within the construction sector, knowing which logistics resources are critical for the implementation of a solution. Urban infrastructure projects require several different vehicles and equipment, like excavators, cranes, trucks, and in the case of Amsterdam, barges are required. Coordination of equipment and vehicles within a city will ensure that they are available when needed. Also, the materials that are being transported to site are critical in terms of quantities, type and delivery time. Managing them collectively will ensure that materials arrive on site on time and in the right quantities. In the analysis the type of material is recorded. The analysis revealed a higher potential for bundling of non-bulk materials. Bulk items were typically transported more efficiently and are more challenging to bundle. The analysis also highlighted the imbalance of materials streams. Half of the vehicles are returning empty, resulting in an inefficient use of resources. A material stream that could be combined to overcome this imbalance is the collection of waste materials.
Another aspect that can be considered a resource is storage space. The more space, the easier it is to store materials for longer. This will increase the flexibility in terms of material deliveries. However, the space in urban areas is usually limited. Working efficiently with the limited space available is therefore another crucial logistics resource. Collaboration between contractors in available storage space could provide benefits in terms of flexibility for all participants involved. To summarize, the critical logistics resources are:

- Equipment and vehicles
- Non-bulk Materials / Waste

- Storage space

RQ 3. Which information/data is required to manage critical logistics resources digitally?
To be able to manage these critical logistics resources, a centralised system is proposed that provides access to standardised logistics information to participating parties. The system should comprise of:

- Transportation and logistics data: information about routes, transportation modes, logistics providers and maximum load capacity
- Material data: type and quantity

This information is considered essential to cover the basic needs for a centralized system that contributes to optimizing resource management in logistics. This data was also used for the analysis of this study. Hence, the data does exist, and for the purpose of reducing empty vehicle movements it has turned out to be sufficient information. However, the road to retrieving this data has taken more energy than one would expect. Due to the current state of digitalization at smaller sized construction companies, data is insufficiently recorded in a digital way. Therefore, obtaining this data is an important step forward to optimizing logistics. So, what is currently missing, but required to manage critical logistic resources is the gathering and recording of data on a large scale which can be used for data analysis. Barriers that contractors are currently facing to gather data needs to be tackled before further steps can be taken. Besides that, additional data could be added to extent the application. The following could be considered further:

- Inventory Management: tracking the availability of resources and ensure that they are distributed to the right place at the right time.
- Historical data: analysing past performance and identify patterns or trends that can be used to improve logistics operations in the future.
- Real-time tracking; used to monitor the movement of resources.
- Customer and supplier data: contact information, order history and delivery preferences.
- Data analytics: used to make sense of data, identify patterns and trends, improve decision making process.

RQ 4. Which results can be achieved through the process?
The initial aim of this study was to prove that by managing resources collectively with other parties, logistics can be optimized resulting in a reduction of emissions. Therefore, an analysis has been done to show that the logistics within the construction industry could be optimized. As discussed in Chapter 7, the results achieved through this process is a reduction of 7% in terms of unused tonne-kilometres compared to the initial state. In other words, traffic is reduced, more specifically traffic that would be empty. This result is achieved through simulating logistic transports of three construction projects. However, more projects are taking place at the same time. Increasing the number of projects would also increase the number of combinations for interventions. Suggesting that a larger pool of projects would result in a higher possibility for optimization.
Another result that was expected, and with this analysis confirmed, is the imbalance between incoming and outgoing material flows. Construction sites are typically material consuming. Waste at the other hand is only applicable in certain stages of a project, like the demolishing. Getting these two streams aligned could solve this imbalance. Projects that are in the construction phase could collaborate with projects in demolishing phase, such that both

transport streams will be used. Also, the analysis displayed that bulk materials tend to be transported quite efficiently while non-bulk materials could be less efficient. This provides us the information that is needed to give focus on future solutions. Optimizing the logistics flow of non-bulk materials will be most effective. Other than these verified results, there are some other effects that could be confirmed based on logical reasoning. These effects are appealing for further research to determine if logical reasoning holds up:

- Reduced energy consumption.
- Reduced CO2 emissions and GHGs.
- Reduced nuisance in the city.

RQ 5. Is the implementation what the user wants?
In the requirements analysis three types of requirements were defined, creating a hierarchy which goes from abstract needs to specified requirements. To answer this question, the user requirements that have been defined in Section 5.2 are up for discussion. The prioritized user requirement is the "Insight in transport of surrounding projects". Figure 20 displays the hierarchy of user requirements towards a BIM integrated system. In this study, the first step has been achieved by creating a database, simulating the centralised system of construction logistics data from three different projects.

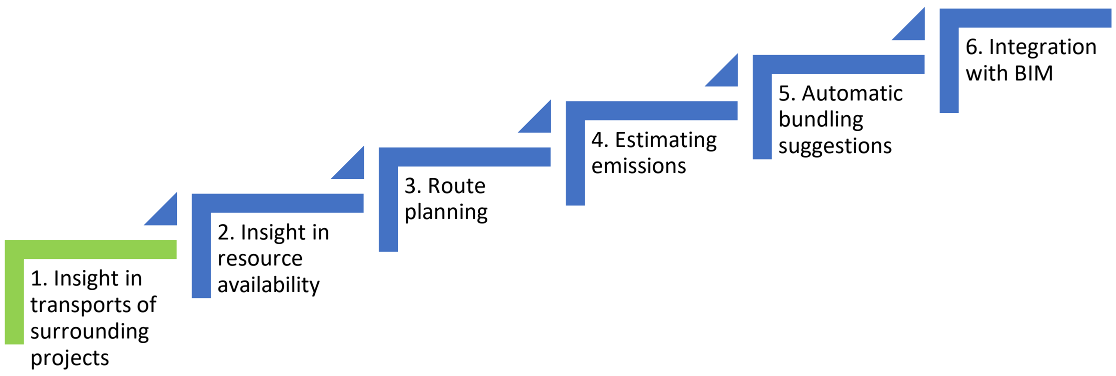

Figure 20. User Requirements Process Steps

The primary requirement had to contain the following items:

a. Weight/Volume of transport
b. Vehicle Dimensions
c. Load factor of transport
d. Resources which are transported
e. Origin and destination of transport
f. Date and time of transport

This corresponds with the data used in the simulation. It shows that this data is sufficient to find new insights in construction logistics data. However, further development is needed to cover the remaining 5 steps towards the integration with BIM. The business requirements consider a more abstract level. From a contractor perspective the business requirement is to reduce logistics costs and environmental footprint. From the perspective of the municipality of Amsterdam, which wants to provide a liveable city to its citizens, the business requirement is reducing the amount of traffic caused by the construction sector. Both can be achieved when the unused tonne-kilometres of vehicles are reduced. This is done by optimizing resource management between multiple urban construction projects. The simulation of interventions provides a proof-of-concept, demonstrating a positive result on the amount of traffic required in urban areas by managing logistic resources in a centralised system.

7.5. Main Research Question

The primary focus of this study is to answer the main research question, which is "How can resource management be optimized between multiple urban construction projects?" The hypothesis suggested for this research proposes that resource management can indeed be optimized, and a centralized management system could be instrumental in achieving this objective. Through an in-depth exploration of this research question, this study aims to provide insights into how collaborative approaches to logistic resource management can be employed to improve the balance between ingoing and outgoing transports, reduce traffic required for construction projects, and optimize resource usage.

The research delved into the current practices in the construction industry. The statement that the industry is slow to adopt digital advancements, seems to be correct. Contractors involved in small to medium sized infrastructural projects have a less advanced approach towards digitalisation, with no specific software used for logistic planning. There is also no standard in keeping track of transport records of projects or communication. Smaller sized contractors do not have the financial resources to operate with more advanced tools. This lack of digitalisation is evident in the industry. To optimize resource management between multiple urban construction projects, it is important to address this lack of digitalization and standardization in the industry. Also, collaboration between stakeholders is essential to coordinate efforts and improve resource management. Critical logistics resources, such as transportation, material, and storage space, should be managed collectively. A centralised system that provides access to standardized logistics information should be implemented to manage these resources effectively. The analysis in this research shows that the logistics within the construction industry could be optimized by the application of a centralised system which takes the data of transports and transported material into consideration. This resulted in a reduction of unused tonne-kilometres by 7%. In other words, contributing to reducing traffic within an urban area.

8. Discussion

The Discussion chapter serves as a dialogue between the findings of the research and the existing literature. It aims to verify and validate the results obtained from the study and to provide recommendations for future research and practical application. This chapter addresses the limitations of the research and explores ways in which they can be addressed in future studies.

8.1. Dialogue

The issue at hand is the slow adoption of digital resource management in the construction industry, particularly among small to medium-sized companies. The contractors' approach towards digitalization is consistent with existing literature, which indicates that the industry is slow to embrace digital advancements. The interviews conducted with contractors suggest that smaller companies face even greater challenges in adopting digital technologies, likely due to the investment costs associated with these technologies. While digitalization is essential for improving efficiency and productivity in the construction industry, many small to medium-sized companies are unable to afford the high costs of implementing and maintaining these technologies. This lack of investment can result in a significant disadvantage for these companies, as they may be unable to keep up with larger competitors who have already embraced digitalization.

To address this challenge, it is important for smaller sized construction companies to explore alternative options for digital resource management that are affordable and accessible. This could include using open-source software or cloud-based tools that require minimal investment in hardware and infrastructure. A great example is the SOK agreement, where smaller sized companies are willing to invest time into new collaborations and look for alternative ideas to set up accessible tools to facilitate resource management.

The lack of standardization due to the fragmented nature of the industry, short-term project focus, limited technology adoption, and limited collaboration are all common challenges highlighted in previous research. The current research findings align with existing literature on resource management in construction, which also identifies equipment, vehicles, and storage space as critical logistics resources. However, the significance of storage space in urban construction projects is often underestimated in the literature. This study highlights the importance of storage space and the challenges it presents, especially in urban areas where space is limited, and efficient use of space is crucial.

An interesting discovery made during the analysis, which has not been extensively discussed in the literature, is the impact of the type of material on optimization potential. Bulk items have been found to be generally transported with high efficiency. On the other hand, non-bulk materials have a higher potential for improvement and are therefore a critical resource that requires collective management.

Furthermore, waste management is another critical aspect that needs to be addressed in urban construction logistics. As highlighted in the analysis, many vehicles return empty from project sites, resulting in an inefficient use of resources. Therefore, managing waste streams collectively could lead to a more sustainable and efficient logistics system within urban areas. Further research needs to be done to identify the most efficient way of collecting and disposing of waste materials in a collaborative manner. This could include exploring the possibility of setting up shared waste collection points, establishing partnerships with waste management companies, or developing new technologies for waste management.

The study recommends a centralized system for managing critical logistics resources, which includes standardised transportation and material data. The required data is not surprising, as it already exists. However, the challenge lies in gathering it on a large scale due to limited digitalisation at smaller-sized construction companies. This challenge is consistent with the literature and discussed earlier. Furthermore, the benefits of interorganizational collaborations have been extensively discussed in the literature. Numerous examples have been provided, ranging from the establishment of consolidation centres to the sharing of resources and information. However, one major obstacle to the success of these collaborations is interoperability. In other words, a unified approach is required to ensure that all parties involved can work together seamlessly and effectively. This entails not only technological compatibility but also organizational and cultural alignment. While many studies have emphasized the importance of interoperability, there is still a lack of practical guidance on how to achieve it. Therefore, further research and efforts are needed to develop a comprehensive framework for achieving interoperability in interorganizational collaborations.

8.2. Verification

Verification refers to the process of checking and verifying that the research study has been conducted according to the established procedures. The process involves comparing the results with known values, data, or expected outcomes to ensure that the results are correct and can be relied upon.

For the verification of the implementation, the interventions have been checked whether they contribute to reducing the unused tkm value. There are three stages compared with each other: the initial stage, the possible stage, and the Control Tower stage. The initial stage represents the current situation. The possible stage represents the optimizations that would currently be possible when applying the interventions, without having to interfere a project schedule. The Control Tower stage represents the optimizations that would have been possible if a Control Tower would control the planning of different projects and could interfere within a project schedule to optimize transports.

To determine how much unused tkm can be reduced, the calculations considered the shortest distance over water or shortest route over road.

Table 7. Saved unused tkm per stage

Stage	Saved unused tkm	% of total unused tkm
Initial (= 15.235 tkm)	0	-
Possible	1000	7 %
Control Tower	1135	7 %
Total	2135	14 %

The results of this verification are displayed in Table 7. Following the transport records, a total of 15.325 tkm is unused. With the interventions that could already be applied without inferring the project schedule, 7% of the unused tkm can be reduced. Adding the effects of a control tower, another 7% can be reduced. Summing up to a total of 14% reduction in the unused tkm. To put that into perspective, on average 206 tkm per transport is unused. Meaning that approximately 10 transports could have been reduced from a total of 165 transports.

8.3. Validation

This section addresses the validity of the research. Reflecting on the validity of the results is crucial for determining the credibility of the findings. A distinction is made between measurement, internal and external validity. These are discussed separately in the following sections.

8.3.1. Measurement Validity

The reliability of the measurements is determined by the quality of the measurements. Therefore, critically reflecting to how the measurements have been realised is of importance. In total there were three samples from different contractors. It contained historical transport records for infrastructural projects that recently had been carried out. Because these records have been measured outside the control of this research, it is challenging to determine the validity of these measurements. For the volumes being transported, different sources of data were used. Transport receipts specified the exact amount of weight and the time of delivery. But the weekly reports received from another contractor does not clearly specify the time of delivery. In that case, assumptions were made. Besides, it could be that instead of a recorded weight, the volume had been recorded. These measurements had to be converted to weights such that all transport records contained the same variables. Assumptions were made to produce these conversions.

8.3.2. Internal Validity

Internal validity describes the extent to which a study can rule out alternative explanations for its findings. Naturally for a cross-sectional research design it is difficult to establish a causal direction from the resulting data. Since cross-sectional research designs produce associations rather than findings from which causal conclusions can be made. Nonetheless, to increase the internal validity, the interventions that have been proposed are discussed with a group of experts. Their feedback determines whether the results are plausible or not. To validate the findings of the analysis a final meeting with the contractors, consultant and the municipality is held. In Table 8 the companies that attended the meeting are provided. In Appendix A the representatives can be found.

Table 8. Attendees Validation Meeting

#	**Company**
1	Beens Groep (1st)
2	Beens Groep (2nd)
3	Dura Vermeer
4	Rutte Groep / City Barging
5	dutch process innovators
6	Gemeente Amsterdam

In this meeting a presentation is provided entailing a short introduction to the overall research, as well as an explanation of what happened with the data that was gathered. At the end of the meeting the proposed interventions are discussed to lay bare any limitations or particularities. Firstly, the 50% load factor of the return is questioned. A representative from Rutte, addressed that their transports always returned empty, typically resulting in an average load factor of 50%. For Beens this number has been reduced to 16%. The experts confirmed that there is a higher number of transports returning empty, simply because there are not always waste streams that can be combined. They were not surprised by the pie charts (Figure 18 & Figure 19) presented on page 33.

Next, the combinations of transports between contractors were discussed. Going through the examples, several relevant factors are mentioned. Factors which must be considered when applying the proposed interventions are:

- The **specific time** (with regards to the communication related to shipping).
- A **distinction** between bulk and general cargo.
- Whether there is sufficient **storage capacity** on site,
    - for earlier arrival of products.
    - for transfer of materials/equipment.
- **Prioritization** of which materials to unload first.
- and, how information is **communicated**.

Moreover, the application of the Control Tower is discussed. The simulation of the Control Tower considers the possibility that the (transport) planning can be adjusted by several days to facilitate the interventions. From an example between project Herengracht and Gillis there was a 4-day difference between the transports. It has been mentioned that the contractors are not willing to halt their vehicles to prioritize optimal transport schedules. Besides, this difference would be too large according to Beens, due to lack of space. A maximum of 2 days is suggested. Lastly, the question was asked if the information gathered and currently displayed would be sufficient for further development, or if additional information would be interesting for improvement. From the municipality of Amsterdam, a comment was made that it would be interesting to know the dependency of equipment. Aside from that, the attendees confirmed no other information was needed.

8.3.3. External Validity

External validity concerns the generalization of the findings. The timing and randomness of the samples play an important role in the strength of the external validity. The goal of external validation is to ensure that the findings of a study are not specific to the sample or context in which the study was conducted, but rather can be generalized to other situations.

The samples are from a similar period, taking place within a one year's timespan. Because the samples are considering a larger period, around three months, the effect of time dependent results is reduced. Nonetheless, it does not completely rule out the effect timing has on the results. Circumstances could drastically change in a three-month period. One could imagine a certain change in regulation as it comes to transport over water. It could affect the number of transport or the maximum size of vehicles within the city. A reduced vehicle size would probably result in less empty capacity that can be used for bundling of transports. Such changes would then result in different findings. Aside from these drastic changes, the influence of timing within the sample period seems to be limited. Certainly, the results would change if one of the project schedules was changed. Different interventions could be proposed, resulting a different outcome of the results. Yet, the sample period considers multiple months of transport records, which lead to believe that there would not be a significant difference in the outcome. A larger sample size, still containing three projects, would however increase the certainty of that.

The randomness of the sample also contributes to a larger external validity. In this research the samples have been retrieved from contractors of mainly infrastructure projects within the city of Amsterdam. In that manner, the sample is not completely random. However, that was not the intention for this research. A certain level of correspondence is sought such that applying the interventions would be logical. The interventions would not be cogent if projects were in different cities, or if other businesses than contractors were considered. Other businesses would be transporting different types of materials or products that would be harder to consolidate or bundle with the resources of contractors.

To conclude, the findings of this study apply specifically to the construction industry in Amsterdam, where water transportation is heavily promoted. Conducting multiple case studies can increase the sample size and enhance the generalizability of the findings. Our findings are consistent with previous case studies conducted as part of the CLCT research. These findings can be considered a more general representation of previous case studies, which helps to strengthen the validity of the findings.

8.4. Limitations

In this section the limitations of this research are discussed. The goal of this section is to provide a balanced and honest evaluation of the study. This helps to ensure that the findings and conclusions of the study are accurately and fairly represented, and that the limitations of the study are acknowledged and discussed. In addition, it contributes to improving the credibility and transparency of the research and provides valuable insights for future research on this topic.

Firstly, applying a cross-sectional research design has its limitations. The most important limitation is the limited generalizability. The findings from a cross-sectional study may not be generalizable to the broader population. This can be a particular concern if the sample is not representative of the population or if the sample size is small. Moreover, since data is collected at a single point in time, it is not possible to determine cause and effect relationships or to track changes over time. Furthermore, using data samples can be valuable for analyzing and understanding the population, yet several limitations need to be considered. Sampling bias (or biased data) could occur when the data sample does not accurately represent the population. This happens if the sample is not selected randomly, or if certain groups are overrepresented or underrepresented in the sample. Also, the size of the sample can affect the reliability and validity of the findings. Furthermore, the quality and (in)completeness of the data might limit the accuracy of the findings. How these limitations are addressed is explained in Section 8.3.

Because the data gathered from the contractors was not initially intended for this specific research, creating a large enough sample with accurate data has been challenging. For further research on the topic, a more efficient, more accurate analysis could be achieved if there was enough time to gather real time transport data. Moreover, accurate data on the distances of transports were missing. For the distance of transports, it has been assumed that the distance is the shortest route possible between the origin and destination. A more accurate result could be achieved it the distance of transports were recorded.

8.5. Recommendation

In this section, three recommendations are provided that are expected to contribute positively to the further development of a suitable solution:

1. Improve quality of data sample,
2. Promote collaboration,
3. Improve simulation.

The first step in the right direction would simply be recording data digitally in a systematic way. This will solve the lack of useful data that the sector on this scale is facing. Future researchers could then have a more accessible set of data. This has been the main challenge through this research. It was difficult to get access to data because companies were not willing to share it. If they were willing to share, in most cases the data covered not enough information and was not ideal for analysis. Improving the quality of logistic data records would therefore contribute positively to carrying out analyses that can be of higher accuracy and quality.

Collaboration is the goal and has proven to be valuable. Scarcity in resources can be accommodated by idle resources in the surrounding. The contractors should be willing to share their data. In this study the contractors did not have any problem with that, but it is a common statement that contractors do not want to share their data with their competitors. Even though the data required is limited, contractors could still not be willing to collaborate. There are however some ideas to motivate data sharing. Communicating the benefits of data sharing may change the contractor's opinion. For example, by including proof of optimized project planning and coordination. Also offering incentives, such as financial rewards or recognition, can help the contractor to be more willing to collaborate. These incentives could be captured in the tender phase of projects. It would also be wise to invest in training programs for employees to ensure they can effectively use these technologies. By doing so, construction companies can overcome the challenges of digitalization and remain competitive in the industry. Furthermore, developing a culture of collaboration and providing support are ideas to drive data sharing.

More simulations of the interventions are recommended. This would enable the capturing of more matches. In this simulation only three projects were used due to the lack of availability of data. Recording and sharing data will give way to more possibilities towards data analysis. More projects in the simulation are likely to result in a higher number of possible interventions, which would result in a higher reduction of tonne-kilometres.

Further prospects with regards to this topic are:

- further developing of proof of concept,
- adding resource availability as a constraint,
- developing proof of technology,
- expanding features, like optimal route selection.

9. Conclusion

The study aimed to optimize logistics in the construction industry with the goal of reducing emissions. Construction logistics has become an increasingly important issue due to the environmental impact of construction projects, particularly in urban areas. This study specifically focused on the Netherlands, where construction logistics is a significant contributor to transport and has raised concerns about the environmental impact. While many studies have focused on optimizing logistics within a single project, this study emphasized the benefits of collaboration among different projects. The hypothesis proposed earlier in the study was that a centralised resource management system can optimize resource usage and reduce environmental impact. This hypothesis was confirmed based on the findings of the study.

By analysing the construction logistics of three projects in the centre-west area of Amsterdam, this study provided insights into how centralised system for logistic resource management can be employed to reduce traffic required for construction projects, optimize resource usage, and potentially improve the balance between ingoing and outgoing transports. The study involved a simulation of interventions that were applied over the logistic records of the three projects, which resulted in a 7% reduction in unused tonne-kilometres.

The analysis exposed a clear distinction between the load factors of ingoing and outgoing transports to the project sites. This imbalance is caused by a lack of visibility of what is going on within the city. To solve the imbalance, projects could be coordinated based on their construction phase. Coordinating projects based on their construction phase and bundling logistics with other contractors working in the same area is expected to optimize logistics resource usage and reduce empty vehicle movements.
A key finding is the reduced efficiency in terms of load factor for non-bulk material transports. These material streams are showing that optimizing towards a full truck load is still possible, but visibility of this data is missing. This visibility can be provided by simulating the centralised management system. By bundling transports with low load factors taking place on the same day contributes to reducing transports, and therefore traffic within the urban area.

The study also highlighted the challenges in data capturing and the need for a unified digital system for logistic data. A centralised management system has the potential to offer a standardised digital interface, which can facilitate intelligent interventions. To enhance the accuracy and quality of logistics data analysis, the study suggests taking the initial step of improving the quality of digital data records. Collaboration among contractors to share data can help address resource scarcity and improve data access, but this may require incentives and cultural change. By improving data availability and collaboration, a new simulation of interventions can be conducted to capture more matches and potentially reduce more tonne-kilometres.

Concluding, this research contributes to more sustainable and efficient construction logistics in urban areas and highlights the importance of collaboration among different projects in achieving this goal. The study concludes that a centralized system for logistic resource management can provide insight into transport data and could reduce traffic caused by construction projects through facilitating smart interventions.

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Appendices

A. Interviews

To get a better understanding of the stakeholders involved and their current approach in construction logistics, semi-structured interviews were conducted. Questions varied depending on the type of stakeholder. For the contractors involved, three topics were discussed: the current approach of planning logistics, the availability of logistics data, and the usage of logistics IT systems. In case of the logistics services: the current approach of water transport, and the usage of information systems. And for the IT administrator, the current possibilities of IT systems, the interoperability with other systems and multi-project management. In Table 9 an overview is provided of the companies that have been interviewed.

Table 9. Overview conducted interviews with stakeholders

#	**Company**
1	H. van Steenwijk
2	Beens Groep
3	Dura Vermeer
4	PK Waterbouw
5	TiQiT

A.1. Interview Guide - in samenwerking met TNO

Planning-opbouw

1. Hoe ziet de logistieke planning van uw bijdrage / rol in een bouwproject eruit?
    a. Houdt deze planning rekening met voorraden?
    b. Welke software wordt hiervoor gebruikt?
2. Hoe ver van tevoren wordt deze planning gemaakt? Wanneer in de globale planning van een bouwproject wordt u betrokken? (zie figuur 1 voor fasering bouwproject)
    a. Wordt deze periodiek geüpdatet?
    b. Met welke partijen wordt deze planning gezamenlijk opgesteld en/of afgestemd?
    c. Welke beperkingen/randvoorwaarden komen uit de aanbesteding (zie: voorbereidingsfase)?
3. Wat zijn de uitgangspunten / randvoorwaarden / eisen ten aanzien van de planning?
    a. Welke informatie-elementen zijn hiervoor nodig?
    b. Wie kan deze informatie leveren (welke organisatie)?
    c. Welke informatie-elementen zijn wenselijk maar op dit moment niet beschikbaar? Wie heeft deze informatie wel?
4. Wordt het gebruik van resources gekoppeld aan activiteiten? (zoals mogelijk in MS project)
5. Wordt er momenteel geoptimaliseerd?
    - Ja: wat en hoe?
    - Nee: waarom niet?

Beschikbare data

6. *Al eerder gevraagd: Hoe communiceren jullie met ketenpartners? (antwoord: Telefonisch, mail)*
7. Welke (logistieke) data is beschikbaar voor het opstellen van een logistieke planning?
    a. Doorvraag: Welke categorieën (informatie-elementen) worden onderscheiden? Voor welke categorieën is de informatie beschikbaar? En welke niet? evt. voorbeelden? (zie ook figuur 2 en 3)
    b. In elke fase verschilt het detailniveau van de beschikbare data / gegevens. Kunt u aangeven in welke fase bepaalde informatie-elementen in meer detail beschikbaar komen / nader kunnen worden gespecificeerd?
8. Welke (logistieke) data bent u bereidt te delen met ketenpartners? Onder welke voorwaarden?
9. Welke (logistieke) data bent u NIET bereidt te delen met ketenpartners? Waarom niet?
10. Van welke softwarepakketten wordt gebruik gemaakt bij het uitwerken van een logistieke planning?

Benodigde data

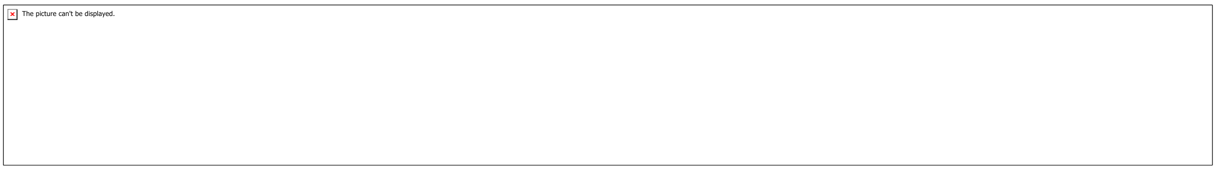
11. Welke (logistieke) informatie is essentieel voor een goede logistieke planning. volgens jou kritiek om te delen?
    a. Doorvraag: Welke categorieën (informatie-elementen) worden onderscheiden? Welke categorieën zijn kritieke informatie-elementen (absoluut noodzakelijk) voor het opstellen van een logistieke planning? evt. voorbeelden?
12. Welke informatie ontbreekt er vaak, die je in jouw opinie nodig is voor een goede logistieke planning / optimalisatie van de logistieke planning?
    a. Waarmee kunnen we de logistieke planning (nog) beter maken? Voorbeeld: Gemeentelijke data, Brughoogtes, Wegcapaciteit, Talking Traffic, stremmingenkaart.

b. Wie beschikt over deze data / informatie?

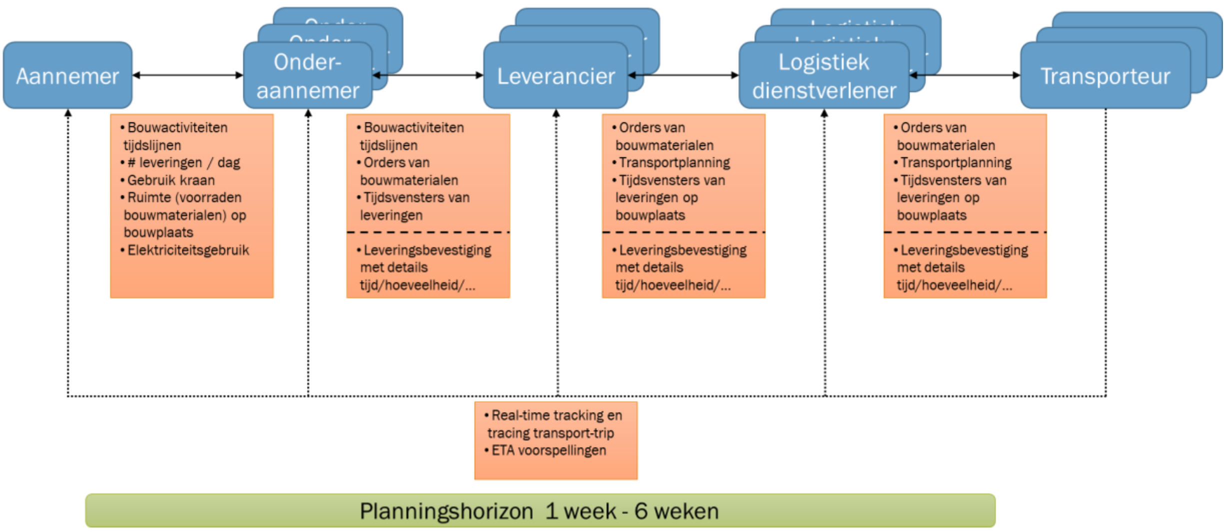
13. Gebruikt u ook externe bronnen?
    a. Welke? (Gemeentelijke data, Brughoogtes, Wegcapaciteit, Talking Traffic, stremmingenkaart)

Functies

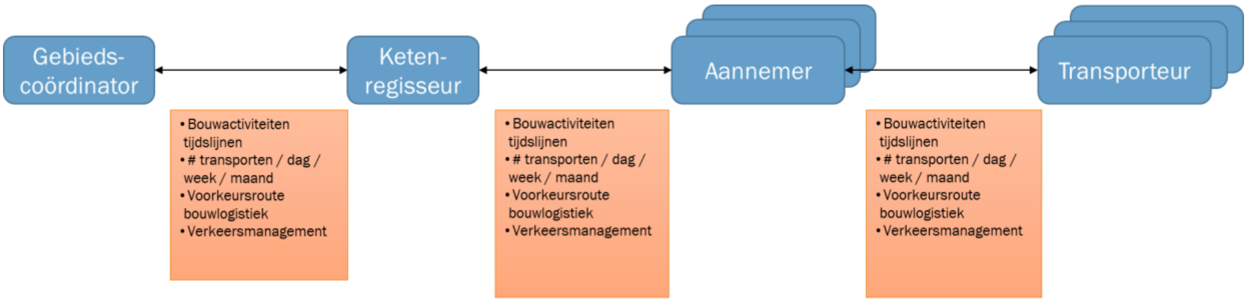
14. Wat zie jij als voornaamste functie van de Bouwlogistieke Control Tower?
    a. 1. (vaar)wegcapaciteit = verkeersmanagement;
    b. 2. bouwmaterialen = logistieke efficientie;
    c. 3. vervoersmiddelen = logistieke asset sharing;
    d. 4. ketenafstemming = productieplanning – transportplanning - bouwplanning.
15. Hoe zou je een Bouwlogistieke Control Tower idealiter gebruiken?
16. Welke functionaliteiten moet Bouwlogistieke Control Tower hebben?
    a. Transportplanning op bouwstromen van en naar bouwproject (2)
    b. Koppeling tussen bouwplanning en transportplanning (en productieplanning) (4)
    c. Kraanplanning (verticaal transport) afstemmen met aflevermomenten (3)
    d. Planning van levervenstertijden en bouwtickets (1, 3)
    e. Voorraadmanagement op bouwplaats / bouwhub (2, 3, 4)
    f. Bundeling / consolidatie planning van transportstromen (bouwhub – bouwplaats) (2)
    g. Planning / samenstelling van (dag/week)-werkpakketten afgestemd op bouwactiviteiten (2)
    h. Realtime tracking&tracing bouwlogistieke ritten (2, 4)
    i. Prestatiemeting van bouwlogistiek (KPI's: emissies, kosten, beladingsgraad, productiviteit, …) (1-4)
    j. Verkeersmanagement / voorkeursrouting bouwlogistiek (1)

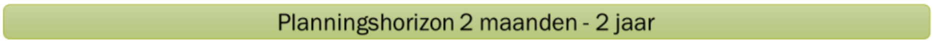


Figuur 1 Fasering bouwproject.



Figuur 2 Informatiestromen bouwlogistieke keten.





Figuur 3 Informatiestromen bouwlogistiek ketenregie op stadsgebied.

A.2. Interview Contractor 1 (H. van Steenwijk)

Planning-opbouw

1. Hoe ziet de logistieke planning van uw bijdrage / rol in een bouwproject eruit?
    a. Houdt deze planning rekening met voorraden?

- "Wat ze vaak willen weten is, hoeveel is het, hoe zwaar, hoeveel keer moeten we varen, dat zijn zaken die de werkvoorbereider allemaal moet uitzoeken en dat afstemmen dan in ons geval met city barging."
- ***Zijn er bepaalde randvoorwaarden, zoals materialen die niet zomaar kunnen worden vervoerd, of waar limieten aan zitten?***
- "Dat heb je inderdaad, iets van damwanden die vaak 18 of 20 meter lang zijn, die moeten in een grotere bak, daar heb je weer ontheffing voor nodig. Maar als je een partij grond of zand moet aan/afvoeren, dat kan binnen de marge van 20 meter."
- ***Wordt er rekening gehouden met wat er op de bouwplaats aanwezig is?***
- "Wij werken voornamelijk vanaf het water, dus wij hebben eigenlijk geen, niet echt, voorraden. Ik kan me wel voorstellen dat er een dekschuit of een beunbak bij hebben liggen voor wat voorraad maar we werken in principe Just-in-time."

* Na terugkoppeling over inzage in logistieke data, blijkt dat de aan en afvoer van materialen niet digitaal is bijgehouden en dat verzoeken vaak nog telefonisch of via de whatsapp worden gecommuniceerd.

    b. Welke software wordt hiervoor gebruikt?

- "Niet hele specifieke software. We maken een planning in MS Project of Primavera en heel veel wordt ook in Excel gedaan."

2. Hoe ver van tevoren wordt deze planning gemaakt? Wanneer in de globale planning van een bouwproject wordt u betrokken? (zie figuur 1 voor fasering bouwproject)
    a. Wordt deze periodiek geüpdatet?
    b. Met welke partijen wordt deze planning gezamenlijk opgesteld en/of afgestemd?
    c. Welke beperkingen/randvoorwaarden komen uit de aanbesteding (zie: voorbereidingsfase)?

- "We werken met een overall planning, en die overall planning wordt weer opgedeeld in een zes weken plannig, die per dag gepland wordt. En als je nu al merkt dat we achterlopen, dan moet je dus ook je logistieke planning aanpassen of versnellingsmaatregelen kiezen in je planning zodat je wel weer je muilpalen haalt."
- "De zes weken planning wordt wekelijks bijgewerkt, elke week plannen we een weekje vooruit in detail. Het blijft een spel van goed vooruit blijven denken en goed afstemmen tussen werkvoorbereider en uitvoerder, en in dit geval ook met de vervoerder, city barging."

3. Wat zijn de uitgangspunten / randvoorwaarden / eisen ten aanzien van de planning?
    a. Welke informatie-elementen zijn hiervoor nodig?
    b. Wie kan deze informatie leveren (welke organisatie)?
    c. Welke informatie-elementen zijn wenselijk maar op dit moment niet beschikbaar? Wie heeft deze informatie wel?

4. Wordt het gebruik van resources gekoppeld aan activiteiten? (zoals mogelijk in MS project)

- “Nee, dat gebeurt echt in Excel in dat soort overzichtjes voor die afstemming.”
- ***Maar die zijn wel op een bepaalde wijze met elkaar gekoppeld?***
- “Nee zo ver zijn we nog niet. We hebben dus in Project de algemene planning gemaakt, en van de uitvoering zijn zes weken planningen. En vanuit daar wordt bepaald wanneer een product nodig is, de werkvoorbereider kan ermee aan de slag.”
- “We hebben nu maar een project lopen, maar ik kan me voorstellen dat we straks toch naar een iets slimmer systeem moeten omdat we straks natuurlijk hoop ik ook meerdere projecten hebben lopen, dat er meerdere stromen door elkaar heen gaan en dat je wel het juiste product bij het juiste project krijgt.”
- ***Ik dus juist aan iets te denken dat je dat op een slimme manier kan koppelen, dat je eigenlijk al weet, die activiteit die heeft die en die resources.***
- “Dat systeem wat jullie dan nu aan het ontwikkelen zijn dat je meteen ziet bij Steenwijk komt dat en dat eraan, dit moet naar dat project. Dat wij het alleen een soort van inkloppen, de gewichten, de volumes.”
- ***En die planningen dus eigenlijk naast elkaar kan leggen. Maar dat is nog een weg te gaan, want hoe krijg je dat tussen al die partijen zo afgestemd?***
- “Ja, hoe ik het voor me zie is dat je gebruik kan maken van elkaars capaciteit. Dat was vorige week ook al een discussie, dat Bart zei ‘ik zie dat niet zitten’, ik had zoiets van ‘waarom zitten we dan bij elkaar, dat is toch juist de hele bedoeling’. Dat ze bij mij wegvaren en ze komen langs het project waar normaal PK voor vaart. Als ik dat dan niet meeneem zegmaar, dan naar mijn zins nog steeds geen nut gehad dat we dit allemaal aan het opzetten zijn. Of je moet het echt per gebied beschouwen maar dan nog zoals Dura, die vaart met PK, Beens heeft veel eigen vaarmaterieel. Volgens mij moet je dat juist combineren. Of dat betekent misschien dat city barging niet op ons project volledig zijn equipment kwijt kan maar dat kan die misschien voor een ander project in Amsterdam. Dan haal je dus veel meer efficiëntie uit je materieel.”
- ***Is dat dan niet zegmaar meer de verantwoordelijkheid van de vervoerder, om dat juist beter af te stemmen tussen verschillende projecten?***
- “Naja kijk, je krijgt dan meteen een aantal praktische zaken. Stel je voor, city barging haalt iets van Dura op, of brengt iets naar Dura, hoe zit het dan verzekeringstechnisch? Ze moeten daarvoor omvaren, hoe gaan die geldstromen dan? Hoe ga je dat registreren, hoe ga je dat bijhouden? Hoe gaan we elkaar dan betalen?”
- ***Nee dat klopt, daar zit ik zelf ook aan te denken, maar aan de andere kant heb ik zoiets van misschien moet ik dat voor nu voor mezelf even nog aan de kant zetten. Want dit is natuurlijk weer een ander onderzoek uiteindelijk, of het contractueel kan en mogelijk is.***
- “Maar hoe ik het begrijp is dat we nu een combinatie willen maken de SOK partners, daar heb je het eigenlijk al, die varen allemaal met andere maatschappijen. Of je gaat varen bij projecten die alleen wij als Steenwijk uitvoeren, heeft het dan nut. Want dat inderdaad, die bij PK en city barging die link kunnen ze zelf wel leggen. Daar hebben ze zelf de software voor. Zo werkt PK, die proberen zo slim mogelijk te varen om zo min mogelijk kosten te maken. Maar het is juist het slimme omdat allemaal te combineren met elkaar en het meeste uit je capaciteit te halen zodat je straks ook, stel Amsterdam ligt in een groot verbouw, er is nu zoveel nodig. Dat is nu al. En er moet ook steeds meer over water.”

5. Wordt er momenteel geoptimaliseerd?
   - Ja: wat en hoe?
   - Nee: waarom niet?

   - "Wij zijn nu nog op een locatie bezig, dus tuurlijk als je slim kan varen dan doe je het maar we hebben op dit moment niet echt mogelijkheden om slim te varen. Straks, het volgende project is dan voor de Melkweg, ten opzichte van de Nieuwe Herengracht ligt dat logistiek gezien heel erg onhandig. Het was handig als het ook op de vaarroute ligt. Als je helemaal moet omvaren om daar dan iets te brengen dan heeft het nog weinig zin daarom moet je denk ik ook per gebied zien."
   - ***Ja of dus inderdaad meerdere partijen erbij betrekken zodat het wel geoptimaliseerd kan worden.***
   - "Ja precies, inderdaad als een Dura of een Beens ook vlak bij die Nieuwe Herengracht bezig is, dan heeft het nut. Dan wordt er bij mij iets gebracht, en moet die terug, ga dan even langs Beens en haal daar hun afval op."
   - ***Ik zou zeggen, dat moet mogelijk zijn.***
   - "Volgens mij is dat de hele bedoeling van dit, en als je dit systeem kan opzetten voor alleen de SOK partners, dan begin je dan een soort van klein. En dan kan je het ook makkelijk uitbreiden naar ook met andere projecten en opdrachtnemers, die ook van het water gebruik moeten maken. Dan heb je iets waardevols in handen.
   - Ik zit zelf ook te denken van, is het dan als product als toekomst resultaat, is het dan een idee om iets te hebben waarin je kan zien 'deze aannemer heeft deze capaciteiten, wordt niet helemaal benut, de overige capaciteit die wordt dan online op een soort van website, of ergens aangeboden waar andere aannemers op in kunnen spelen. Zodat je bijvoorbeeld je materieel aanbiedt die je niet gebruikt, en dat je het eigenlijk een soort van verhuurt. Dat het inzichtelijk is wat een aannemer beschikbaar heeft en dat vervolgens aanbiedt aan de rest om te kunnen kijken van oke, wij hebben dit op dit momenten, dat is al in de stad, dat kan nu gebruikt worden.
   - "Het is alleen dat elke aannemer het liefst zijn eigenlijk materieel wilt laten varen, want dat levert vaak geld op. Stel je voor, je hebt een boot gekocht, een beunboot, die is al 20 jaar oud en daar schrijf je niks meer op af. Uberhaubt, je wilt gewoon je eigen materieel laten varen want dat levert geld op.
   - ***Niet dat je het van een ander pakt en het betaalt.***
   - Precies, en dan als je zegt nee ik gebruik van een andere capaciteit, dat betekent dus wat jij hebt varen dan misschien stil ligt, en dat wil je niet. Je wilt alleen je eigen materieel laten varen, dat levert je geld op. Of je materieel wordt ervan betaald.
   - ***Eigenlijk is het dan ook een soort van stimulans om dan juist wel je materieel uit te lenen.***
   - Ja, dat denk ik wel. Ik denk dat het op zich niet zoveel uitmaakt, wat erin zit en van wie, als het maar blijft varen. Dan moet je dus kijken hoe werkt dat met betalen. Wij hebben bijvoorbeeld een haven ergens in Zaandam, als we iets moeten brengen bij de haven van PK of van het Hek of ergens anders, dan moeten ze een omweg doen, zijn ze langer bezig. Wie betaalt die tijd? Zo zitten de aannemers er wel in he, het draait altijd om geld. Iedereen wilt gewoon geld verdienen eraan. (16;00)

Beschikbare data

6. *Al eerder gevraagd: Hoe communiceren jullie met ketenpartners? (antwoord: Telefonisch, mail)*
7. Welke (logistieke) data is beschikbaar voor het opstellen van een logistieke planning?

a. Doorvraag: Welke categorieën (informatie-elementen) worden onderscheiden? Voor welke categorieën is de informatie beschikbaar? En welke niet? evt. voorbeelden? (zie ook figuur 2 en 3)
b. In elke fase verschilt het detailniveau van de beschikbare data / gegevens. Kunt u aangeven in welke fase bepaalde informatie-elementen in meer detail beschikbaar komen / nader kunnen worden gespecificeerd?

- Wat je vervoert, wanneer je het vervoert, hoeveel logistieke bewegingen je hebt. Route is ook belangrijk. Of die leeg teruggaat, zodat iemand dus van die capaciteit gebruik kan maken. Emissies. Laad- en losmethoden, het moet er natuurlijk ook weer uit. Equipment wat zeg maar daar aan de loskade staat die moet dat wel kunnen handelen, en soms heb je iets heel specifieks, iets heel groots, waar soms ook wel eens aparte kranen voor worden gehuurd.
- ***Is er een machine aanwezig om de boot om te laden en lossen?***
- Nee, dat is inderdaad een boot met een bak. En dan wordt het op locatie waar het heen of terugvaart daar wordt het dan gelost. Op de loskade staat dan ook vaak een kraan. Bij een project staat vaak een kraan op een ponton op het water, die hem dan kan lossen. Het is dan wel belangrijk om te weten wat er wordt vervoerd, is het een pallet of is het los zand.
- ***Zit daar een standaardtaal achter?***
- Niet dat ik weet, maar je zou zoiets kunnen standaardiseren en categoriseren.
- ***Niet dat de ene aannemer een materiaal aanbiedt maar dat het anders wordt geïnterpreteerd door de andere aannemer. Dat daar wel gewoon dezelfde communicatie achter zit.***
- Precies, of de losmethode. Of je spreekt af dat als je alles wilt kunnen lossen, dan heb je standaard deze equipment nodig op je werk. Of dat je zelf beperkingen opgeeft in je logistiek. Deze aannemer heeft dit op zijn werk staan, we kunnen maximaal dit gewicht voor hem meenemen.

8. Welke (logistieke) data bent u bereidt te delen met ketenpartners? Onder welke voorwaarden?
9. Welke (logistieke) data bent u NIET bereidt te delen met ketenpartners? Waarom niet?
10. Van welke softwarepakketten wordt gebruik gemaakt bij het uitwerken van een logistieke planning?

- MS Project / Primavera / Excel

Benodigde data

11. Welke (logistieke) informatie is essentieel voor een goede logistieke planning. volgens jou kritiek om te delen?
    a. Doorvraag: Welke categorieën (informatie-elementen) worden onderscheiden? Welke categorieën zijn kritieke informatie-elementen (absoluut noodzakelijk) voor het opstellen van een logistieke planning? evt. voorbeelden?

- Zie bovenstaande, geen aanvulling.

12. Welke informatie ontbreekt er vaak, die je in jouw opinie nodig is voor een goede logistieke planning / optimalisatie van de logistieke planning?
    a. Waarmee kunnen we de logistieke planning (nog) beter maken? Voorbeeld: Gemeentelijke data, Brughoogtes, Wegcapaciteit, Talking Traffic, stremmingenkaart.

b. Wie beschikt over deze data / informatie?

13. Gebruikt u ook externe bronnen?

a. Welke? (Gemeentelijke data, Brughoogtes, Wegcapaciteit, Talking Traffic, stremmingenkaart)

- ***Gebruiken jullie 3D software?***
- Niet voor de logistiek. Ook nog niet voor het ontwerp, dat gaan we wel doen. Maar nog niet voor de logistiek, dat is tot nu toe allemaal gewoon simpele 2D faseringstekeningen, is dat allemaal uitgewerkt. We maken het wel allemaal visueel, welk ruimtebeslag heb je nou nodig en hoe ziet dat er dan uit. Met vaarroutes ook van scheepvaartverkeer erachter langs. Gewoon heel simpel plattegronden en in principe is dat voldoende. 3D heeft hier niet echt een toegevoegde waarde.
- ***Is GIS nog relevant, qua routes, aanvoer?***
- Misschien wel qua routes, breedtes, dieptes, ja dat wel. Daar wordt nu niks mee gedaan. Nu spreken we gewoon met city barging af, zorg dat het er komt, even simpel gezegd, dat hebben we nodig, regel het maar.
- In dit geval hebben we het dus weggelegd bij city barging en worden we dus een soort van ontzorgd. Maar dat hebben we in het verleden wel allemaal zelf moeten organiseren. En gaan wel in onderhandeling met waternet, zeker op wat logistiek lastige locaties, bijvoorbeeld een Grimburgwal in Amsterdam, dat zit echt hartje centrum, waar de kademuur 2 jaar geleden is ingestort. Dan moet je wel echt in onderhandeling en kijken naar de logistieke routes en beperkingen en wat moet er eventueel nog langs gaan. Waar we nu op de Nieuwe Herengracht zitten, is een doorgaande route voor scheepvaart en rondvaartboten voor Amsterdam in en uit. Dus die moet altijd openblijven en daar hebben we ook afspraken over. Maar dat zijn ook belangrijke zaken, wat zijn de beperkingen van de stakeholders, wat geeft waternet op van mate maar ook in tijden. Je mag niet zomaar overal in Amsterdam varen, sommige routes wel maar niet overal. Dan zou je ontheffingen moeten aanvragen. Of je mag varen tussen bepaalde tijden, en daarbuiten moet je er weg zijn.

A.3. Interview Contractor 2 (Beens)

Planning-opbouw

1. Hoe ziet de logistieke planning van uw bijdrage / rol in een bouwproject eruit?
    a. Houdt deze planning rekening met voorraden?
    b. Welke software wordt hiervoor gebruikt?

- Planning houdt geen rekening met voorraad;
- er wordt geen planningspakket (software) gebruikt;
- eerst wordt een grove planning gemaakt, daarna volgt een planning in meer detail;

2. Hoe ver van tevoren wordt deze planning gemaakt? Wanneer in de globale planning van een bouwproject wordt u betrokken? (zie figuur 1 voor fasering bouwproject)
    a. Wordt deze periodiek geüpdatet?
    b. Met welke partijen wordt deze planning gezamenlijk opgesteld en/of afgestemd?
    c. Welke beperkingen/randvoorwaarden komen uit de aanbesteding (zie: voorbereidingsfase)?

3. Wat zijn de uitgangspunten / randvoorwaarden / eisen ten aanzien van de planning?
    a. Welke informatie-elementen zijn hiervoor nodig?
    b. Wie kan deze informatie leveren (welke organisatie)?
    c. Welke informatie-elementen zijn wenselijk maar op dit moment niet beschikbaar? Wie heeft deze informatie wel?

4. Wordt het gebruik van resources gekoppeld aan activiteiten? (zoals mogelijk in MS project)

- Nee;

5. Wordt er momenteel geoptimaliseerd?
    - Ja: wat en hoe?
    - Nee: waarom niet?

Beschikbare data

6. *Al eerder gevraagd: Hoe communiceren jullie met ketenpartners? (antwoord: Telefonisch, mail)*
7. Welke (logistieke) data is beschikbaar voor het opstellen van een logistieke planning?
    a. Doorvraag: Welke categorieën (informatie-elementen) worden onderscheiden? Voor welke categorieën is de informatie beschikbaar? En welke niet? evt. voorbeelden? (zie ook figuur 2 en 3)
    b. In elke fase verschilt het detailniveau van de beschikbare data / gegevens. Kunt u aangeven in welke fase bepaalde informatie-elementen in meer detail beschikbaar komen / nader kunnen worden gespecificeerd?

8. Welke (logistieke) data bent u bereidt te delen met ketenpartners? Onder welke voorwaarden?

- Data delen niet echt een probleem.

9. Welke (logistieke) data bent u NIET bereidt te delen met ketenpartners? Waarom niet?

   - Niet van toepassing

10. Van welke softwarepakketten wordt gebruik gemaakt bij het uitwerken van een logistieke planning?

- Geen gebruik van softwarepakketten

Benodigde data

11. Welke (logistieke) informatie is essentieel voor een goede logistieke planning. volgens jou kritiek om te delen?
    a. Doorvraag: Welke categorieën (informatie-elementen) worden onderscheiden? Welke categorieën zijn kritieke informatie-elementen (absoluut noodzakelijk) voor het opstellen van een logistieke planning? evt. voorbeelden?
12. Welke informatie ontbreekt er vaak, die je in jouw opinie nodig is voor een goede logistieke planning / optimalisatie van de logistieke planning?
    a. Waarmee kunnen we de logistieke planning (nog) beter maken? Voorbeeld: Gemeentelijke data, Brughoogtes, Wegcapaciteit, Talking Traffic, stremmingenkaart.
    b. Wie beschikt over deze data / informatie?
13. Gebruikt u ook externe bronnen?
    a. Welke? (Gemeentelijke data, Brughoogtes, Wegcapaciteit, Talking Traffic, stremmingenkaart)

Functies

14. Wat zie jij als voornaamste functie van de Bouwlogistieke Control Tower?
    a. 1. (vaar)wegcapaciteit = verkeersmanagement;
    b. 2. bouwmaterialen = logistieke efficientie;
    c. 3. vervoersmiddelen = logistieke asset sharing;
    d. 4. ketenafstemming = productieplanning – transportplanning - bouwplanning.

   - 4. ketenafstemming = productieplanning – transportplanning - bouwplanning.

15. Hoe zou je een Bouwlogistieke Control Tower idealiter gebruiken?

- Het zelf inzichtelijk kunnen krijgen van welke transporten er worden gevaren zodat dit beter kan worden afgestemd.

16. Welke functionaliteiten moet Bouwlogistieke Control Tower hebben?
    a. Transportplanning op bouwstromen van en naar bouwproject (2)
    b. Koppeling tussen bouwplanning en transportplanning (en productieplanning) (4)

A.4. Interview Contractor 3 (DuraVermeer)

Planning-opbouw

1. Hoe ziet de logistieke planning van uw bijdrage / rol in een bouwproject eruit?
    a. Houdt deze planning rekening met voorraden?
    b. Welke software wordt hiervoor gebruikt?

- er wordt geen planningspakket (software) gebruikt;
- huidige werkwijze: er wordt voor de komende 3 weken een planning gemaakt voor de transporten op dag/week niveau, met daaraan gekoppeld de ‘middelen’ die nodig zijn (duwbakken. sleep- en duwboten en personeel); zie ook planningsvoorbeeld;
- deze planning wordt gedeeld via email met leveranciers en logistiek dienstverleners en de waterwegbeheerder;

2. Hoe ver van tevoren wordt deze planning gemaakt? Wanneer in de globale planning van een bouwproject wordt u betrokken? (zie figuur 1 voor fasering bouwproject)
    a. Wordt deze periodiek geüpdatet?
    b. Met welke partijen wordt deze planning gezamenlijk opgesteld en/of afgestemd?
    c. Welke beperkingen/randvoorwaarden komen uit de aanbesteding (zie: voorbereidingsfase)?

- in huidige situatie wordt niet ver vooruit gepland, tijdshorizon voor planning is ongeveer 3 weken;
- er wordt afgestemd met waterwegbeheerder (gemeente Amsterdam) voor vervoer over water via email / telefoon;
- afstemming vindt plaats met nautisch dienstverlener / logistiek dienstverlener en de leverancier;

3. Wat zijn de uitgangspunten / randvoorwaarden / eisen ten aanzien van de planning?
    a. Welke informatie-elementen zijn hiervoor nodig?
    b. Wie kan deze informatie leveren (welke organisatie)?
    c. Welke informatie-elementen zijn wenselijk maar op dit moment niet beschikbaar? Wie heeft deze informatie wel?

- bij planning van transport over water vormt het bulkvervoer van ‘vervuilde’ grond een extra moeilijkheidsgraad, aangezien de duwbak daarna gereinigd moet worden

4. Wordt het gebruik van resources gekoppeld aan activiteiten? (zoals mogelijk in MS project)

- zie planningsvoorbeeld van de uitvoerder (Vincent van Velse) – dag- / weekplanning met materieel (duwbakken, sleep- en duwboten) die ingezet worden;

5. Wordt er momenteel geoptimaliseerd?
- Ja: wat en hoe?
- Nee: waarom niet?

- er vindt optimalisatie plaats door de planners zelf niet ondersteund met planningssoftware en/of algoritmes;

Beschikbare data

6. *Al eerder gevraagd: Hoe communiceren jullie met ketenpartners? (antwoord: Telefonisch, mail)*
7. Welke (logistieke) data is beschikbaar voor het opstellen van een logistieke planning?
    a. Doorvraag: Welke categorieën (informatie-elementen) worden onderscheiden? Voor welke categorieën is de informatie beschikbaar? En welke niet? evt. voorbeelden? (zie ook figuur 2 en 3)
    b. In elke fase verschilt het detailniveau van de beschikbare data / gegevens. Kunt u aangeven in welke fase bepaalde informatie-elementen in meer detail beschikbaar komen / nader kunnen worden gespecificeerd?

- huidige detailniveau is planning op dag- / weekbasis van de inzet van materieel (duwbakken, sleep- en duwboten); zie planningsvoorbeeld van de uitvoerder (Vincent van Velse);
- diepgang van planning is reserveren / huren van materieel (duwbakken, sleep- en duwboten) en personeel op dagbasis;

8. Welke (logistieke) data bent u bereidt te delen met ketenpartners? Onder welke voorwaarden?
9. Welke (logistieke) data bent u NIET bereidt te delen met ketenpartners? Waarom niet?
10. Van welke softwarepakketten wordt gebruik gemaakt bij het uitwerken van een logistieke planning?

- er wordt geen planningspakket (software) gebruikt;

Benodigde data

11. Welke (logistieke) informatie is essentieel voor een goede logistieke planning. volgens jou kritiek om te delen?
    a. Doorvraag: Welke categorieën (informatie-elementen) worden onderscheiden? Welke categorieën zijn kritieke informatie-elementen (absoluut noodzakelijk) voor het opstellen van een logistieke planning? evt. voorbeelden?
12. Welke informatie ontbreekt er vaak, die je in jouw opinie nodig is voor een goede logistieke planning / optimalisatie van de logistieke planning?
    a. Waarmee kunnen we de logistieke planning (nog) beter maken? Voorbeeld: Gemeentelijke data, Brughoogtes, Wegcapaciteit, Talking Traffic, stremmingenkaart.
    b. Wie beschikt over deze data / informatie?
13. Gebruikt u ook externe bronnen?
    a. Welke? (Gemeentelijke data, Brughoogtes, Wegcapaciteit, Talking Traffic, stremmingenkaart)

Functies

14. Wat zie jij als voornaamste functie van de Bouwlogistieke Control Tower?
    a. 1. (vaar)wegcapaciteit = verkeersmanagement;
    b. 2. bouwmaterialen = logistieke efficientie;

c. 3. vervoersmiddelen = logistieke asset sharing;
d. 4. ketenafstemming = productieplanning – transportplanning - bouwplanning.

- 2. logistieke efficiëntie = transportplanning

15. Hoe zou je een Bouwlogistieke Control Tower idealiter gebruiken?

- eerst registratie van bouwlogistieke gegevens op orde krijgen, zodat inzicht verbetert
- later optimalisatiemogelijkheden onderzoeken en toepassen
- belang om breder af te stemmen zowel in de keten (met ketenpartijen) als over projecten heen (met andere aannemers) wordt onderkend en ondersteund

16. Welke functionaliteiten moet Bouwlogistieke Control Tower hebben?
   a. Transportplanning op bouwstromen van en naar bouwproject (2)
   b. Koppeling tussen bouwplanning en transportplanning (en productieplanning) (4)
   c. Kraanplanning (verticaal transport) afstemmen met aflevermomenten (3)
   d. Planning van levervenstertijden en bouwtickets (1, 3)
   e. Voorraadmanagement op bouwplaats / bouwhub (2, 3, 4)
   f. Bundeling / consolidatie planning van transportstromen (bouwhub – bouwplaats) (2)
   g. Planning / samenstelling van (dag/week)-werkpakketten afgestemd op bouwactiviteiten (2)
   h. Realtime tracking&tracing bouwlogistieke ritten (2, 4)
   i. Prestatiemeting van bouwlogistiek (KPI's: emissies, kosten, beladingsgraad, productiviteit, …) (1-4)
   j. Verkeersmanagement / voorkeursrouting bouwlogistiek (1)

A.5. Interview Logistics Services

Planning-opbouw

1. Hoe ziet de logistieke planning van uw bijdrage / rol in een bouwproject eruit?
    a. Houdt deze planning rekening met voorraden?
    b. Welke software wordt hiervoor gebruikt?

- PKWaterbouw heeft de afgelopen periode geïnvesteerd in een goed werkend informatiesysteem (TiQiT), en heeft er belang bij dat dit verder wordt gebruikt;
- TiQiT geeft inzicht in de planning van transporten voor duwboten/sleepboten uit de vaartuigvloot van PKWaterbouw en de bezetting / planning van de duwboten/sleepboten en overige resources (kranen voor laden/lossen)
- een uitdraai van de transporten (gepland en geregistreerd) is beschikbaar via (TiQiT); neem als voorbeeld het Binx project
- Er zit een voorraadfunctie in TiQiT maar deze wordt niet gebruikt door PKWaterbouw; is (nog) niet relevant om conform een groothandel/leverancier voorraadmanagement te voeren;
- Wat wel belangrijk is, is het managen van de voorraadruimte die nodig is / beschikbaar is; dit gebeurt op basis van vakken (huur van aantal vakken ruimte voor bepaalde/onbepaalde duur);

2. Hoe ver van tevoren wordt deze planning gemaakt? Wanneer in de globale planning van een bouwproject wordt u betrokken? (zie figuur 1 voor fasering bouwproject)
    a. Wordt deze periodiek geüpdatet?
    b. Met welke partijen wordt deze planning gezamenlijk opgesteld en/of afgestemd?
    c. Welke beperkingen/randvoorwaarden komen uit de aanbesteding (zie: voorbereidingsfase)?

- regelmatig (wekelijks) overleg dan wel informatie-uitwisseling tussen alle partijen over logistieke planning is nodig om tot een goede (efficiënte) logistieke uitvoering te komen;
- doorgaans tijdshorizon van 1 week vooruit plannen; voor 'specials' wordt verder vooruit gepland tot 6 weken

3. Wat zijn de uitgangspunten / randvoorwaarden / eisen ten aanzien van de planning?
    a. Welke informatie-elementen zijn hiervoor nodig?
    b. Wie kan deze informatie leveren (welke organisatie)?
    c. Welke informatie-elementen zijn wenselijk maar op dit moment niet beschikbaar? Wie heeft deze informatie wel?

- belang PKWaterbouw ligt voornamelijk in het vullen van de boten uit de vaartuigvloot van PKWaterbouw met volle vrachten; dat is de eerste uitdaging;
- PKWaterbouw ziet wel mogelijkheden om over meerdere projecten optimalisaties van transporten te realiseren, dat is op dit moment nog een uitdaging;
- Informatie-elementen: zie uitdraai TiQiT van Binx project;

4. Wordt het gebruik van resources gekoppeld aan activiteiten? (zoals mogelijk in MS project)

    - TiQiT geeft inzicht in de planning van transporten voor duwboten/sleepboten uit de vaartuigvloot van PKWaterbouw en de bezetting / planning van de duwboten/sleepboten en overige resources (kranen voor laden/lossen)

5. Wordt er momenteel geoptimaliseerd?
    - Ja: wat en hoe?
    - Nee: waarom niet?

    - er vindt optimalisatie plaats door de planners zelf niet ondersteund met planningssoftware en/of algoritmes;

Beschikbare data

6. *Al eerder gevraagd: Hoe communiceren jullie met ketenpartners? (antwoord: Telefonisch, mail)*
7. Welke (logistieke) data is beschikbaar voor het opstellen van een logistieke planning?
    a. Doorvraag: Welke categorieën (informatie-elementen) worden onderscheiden? Voor welke categorieën is de informatie beschikbaar? En welke niet? evt. voorbeelden? (zie ook figuur 2 en 3)
    b. In elke fase verschilt het detailniveau van de beschikbare data / gegevens. Kunt u aangeven in welke fase bepaalde informatie-elementen in meer detail beschikbaar komen / nader kunnen worden gespecificeerd?

    - zie planningsvoorbeeld uitdraai TiQiT van Binx project;

8. Welke (logistieke) data bent u bereidt te delen met ketenpartners? Onder welke voorwaarden?
9. Welke (logistieke) data bent u NIET bereidt te delen met ketenpartners? Waarom niet?
10. Van welke softwarepakketten wordt gebruik gemaakt bij het uitwerken van een logistieke planning?

    - TiQiT;

Benodigde data

11. Welke (logistieke) informatie is essentieel voor een goede logistieke planning. volgens jou kritiek om te delen?
    a. Doorvraag: Welke categorieën (informatie-elementen) worden onderscheiden? Welke categorieën zijn kritieke informatie-elementen (absoluut noodzakelijk) voor het opstellen van een logistieke planning? evt. voorbeelden?
12. Welke informatie ontbreekt er vaak, die je in jouw opinie nodig is voor een goede logistieke planning / optimalisatie van de logistieke planning?
    a. Waarmee kunnen we de logistieke planning (nog) beter maken? Voorbeeld: Gemeentelijke data, Brughoogtes, Wegcapaciteit, Talking Traffic, stremmingenkaart.
    b. Wie beschikt over deze data / informatie?
13. Gebruikt u ook externe bronnen?

a. Welke? (Gemeentelijke data, Brughoogtes, Wegcapaciteit, Talking Traffic, stremmingenkaart)

Functies

14. Wat zie jij als voornaamste functie van de Bouwlogistieke Control Tower?
    a. 1. (vaar)wegcapaciteit = verkeersmanagement;
    b. 2. bouwmaterialen = logistieke efficientie;
    c. 3. vervoersmiddelen = logistieke asset sharing;
    d. 4. ketenafstemming = productieplanning – transportplanning - bouwplanning.

- 2. logistieke efficiëntie = transportplanning
- 3. logistieke asset sharing = inzet van duwbakken en sleepboten

15. Hoe zou je een Bouwlogistieke Control Tower idealiter gebruiken?

- belang PKWaterbouw ligt voornamelijk in het vullen van de boten uit de vaartuigvloot van PKWaterbouw met volle vrachten; dat is de eerste uitdaging;
- PKWaterbouw ziet wel mogelijkheden om over meerdere projecten optimalisaties van transporten te realiseren, dat is op dit moment nog een uitdaging;
- belang om breder af te stemmen en informatie uit te wisselen zowel in de keten (met ketenpartijen) als over projecten heen (met andere aannemers) wordt onderkend en ondersteund

16. Welke functionaliteiten moet Bouwlogistieke Control Tower hebben?
    a. Transportplanning op bouwstromen van en naar bouwproject (2)
    b. Koppeling tussen bouwplanning en transportplanning (en productieplanning) (4)
    c. Kraanplanning (verticaal transport) afstemmen met aflevermomenten (3)
    d. Planning van levervenstertijden en bouwtickets (1, 3)
    e. Voorraadmanagement op bouwplaats / bouwhub (2, 3, 4)
    f. Bundeling / consolidatie planning van transportstromen (bouwhub – bouwplaats) (2)
    g. Planning / samenstelling van (dag/week)-werkpakketten afgestemd op bouwactiviteiten (2)
    h. Realtime tracking&tracing bouwlogistieke ritten (2, 4)
    i. Prestatiemeting van bouwlogistiek (KPI's: emissies, kosten, beladingsgraad, productiviteit, …) (1-4)
    j. Verkeersmanagement / voorkeursrouting bouwlogistiek (1)

A.6. Interview Bouwticket systeem

TiQiT (https://www.tiqit.nl) is een interactie ICT-tool voor bouwlogistiek. TiQiT een applicatie die wordt beheerd/geabonneerd door 1 hoofdgebruiker, die vervolgens bepaalt wie de medegebruikers zijn. De applicatie is verder naar wens uit te breiden.

Dit interview volgt een andere guide dan eerdere interviews omdat het perspectief van deze stakeholder anders is. Het doel van dit interview is kennis op doen, en informatie inzichtelijk krijgen over;

1. De huidige mogelijkheden van ICT-tools
2. De koppeling tussen andere informatiesystemen
3. Het beheren van meerdere projecten

Huidige mogelijkheden ICT	
1. Voorraadmodule – is het mogelijk om voorraad van een andere partij/project in te zien?	Technisch veel mogelijk met ICT
2. Materieelmodule – is het mogelijk om de status van materieel van een andere partij/project in te zien? a. Ook de beschikbaarheid?	Materieel is gereedschap, is complexer vanwege keurdate en gaat veel retour. Beschikbaarheid 6 weken van tevoren lastig te plannen
3. Control Tower – ondersteunt de CT alleen de transporteur(s)? a. Betekent dit dat elke transporteur gratis toegang heeft tot de applicatie?	Theorie is anders dan praktijk Berg informatie ga je delen, wie is erin geïnteresseerd. Interpreteren van data is moeilijk
4. Hoe zit het momenteel met transport over water? a. Heeft dit dezelfde functionaliteit als de transportmodule?	In principe wel
5. Wie kan wanneer bijsturen?	Eigenaar project

6. Zijn er momenteel beperkingen?	
Koppeling	
7. Hoe zit het met de uitwisseling van informatie tussen verschillende partijen? Wordt er een standaardtaal gebruikt?	BIM niet te betalen Wordt allemaal te complex Koppelen met ERP, goed systeem, kan je geen cellen/kolommen verslepen slepen zoals excel. ERP kan je niet kapot maken Geen goed informatiesysteem Betrouwbare data nodig, systemen koppelen niet moeilijk
8. Is er een koppeling met andere informatiesystemen (van gebruiker)? a. Bv. de bouwplanning? b. Bv. Als uitvoering vertraagt, weet de tool dat transport moet worden uitgesteld?	
9. Bestaat er een koppeling met BIM voor bijvoorbeeld het 3D visualiseren van goederentransport op de bouwplaats?	Transport over water is onvoorspelbaarder, GPS
Multi Project	
10. Kan een aannemer vanuit de applicatie meerdere projecten beheren?	De definitie van aansturen; data delen Wat gaat het hem opleveren?
11. Stel dat twee aannemers willen samenwerken in hun transport, is het dan mogelijk om vanuit deze applicatie samen te werken?	
12. Zou de gemeente ook een abonnement kunnen afsluiten en hiermee dus per project toegang kunnen geven tot deze informatie?	

A.7. Validation Meeting Attendees (Confidential)

This Table includes the attendees of the validation meeting held on the 18th of January 2023.

#	**Company**
1	Beens Groep
2	Beens Groep
3	Dura Vermeer
4	Rutte / City Barging
5	dutch process innovators
6	Gemeente Amsterdam

B. Sankey Chart Code

For the Sankey Chart in Figure 14 a tool is used to build it illustration. The tool can be found on the following URL: https://sankeymatic.com/build/

The input for this chart is derived from the data base created in the Excel file. The following code has been written to create the illustration:

```
// Enter Flows between Nodes, like this:
//      Source [AMOUNT] Target

Gilles [1] Attributes
Gilles [1] Various
Gilles [26] Ground
Gilles [3] Rubble
Gilles [3] Stones
Singel [1] Various
Singel [10] Ground
Singel [16] Empty
Singel [1] Equipment
Herengracht [2] Attributes
Herengracht [7] Concrete
Herengracht [2] Big bags
Herengracht [5] Various
Herengracht [4] Ground
Herengracht [1] Wood
Herengracht [12] Empty
Herengracht [2] Equipment
Herengracht [2] Rubble
Herengracht [1] Stones

Attributes [2] In
Concrete [6] In
Big bags [1] In
Various [5] In
Ground [32] In
Empty [7] In
Equipment [1] In
Stones [3] In

Attributes [1] Out
Concrete [1] Out
Big bags [1] Out
Various [2] Out
Ground [8] Out
Wood [1] Out
Empty [21] Out
Equipment [2] Out
Rubble [5] Out
Stones [1] Out
```

In [57] Total Transports
Out [39] Non-reusable
Out [4] Potentially Reusable
Non-reusable [39] Total Transports
Potentially Reusable [4] Total Transports

//Out [43] Total Transports
// You can set a Node's color, like this:
//:Budget #708090
//   ...or a color for a single Flow:
//Budget [160] Other Necessities #0F0

// Use the controls below to customize
// your diagram's appearance...

C. Used Vehicles in Transport Records

In the case study different vehicles were used for transportation over water. These vehicles are called ‘Beunbakken’ which translates to hopper barges (see Figure 21). The following barges were used:

- Beunbak 40 m3
- Beunbak 78 m3
- Beunbak (20 x 4,5m) ≈ 80 m3

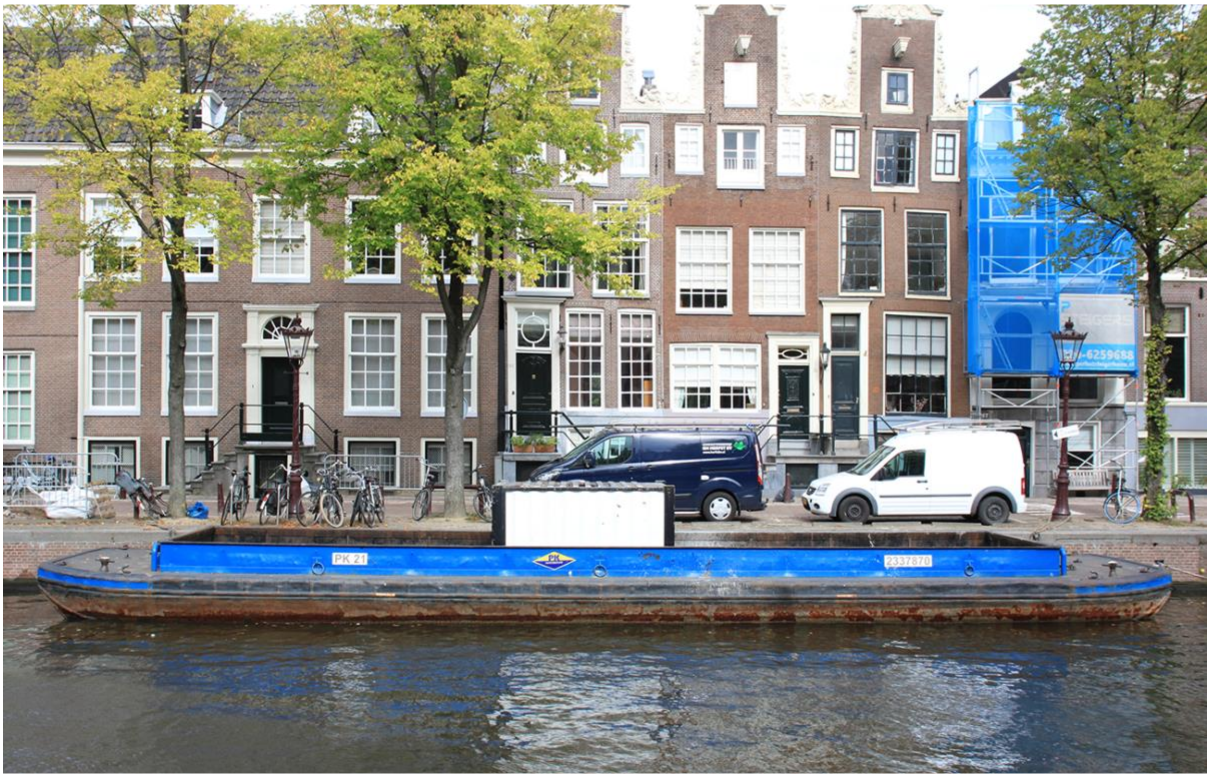


Figure 21. Example hopper barge used by PK waterbouw

(Source: https://pkwaterbouw.nl/pontons-ruim-en-dekschepen/)

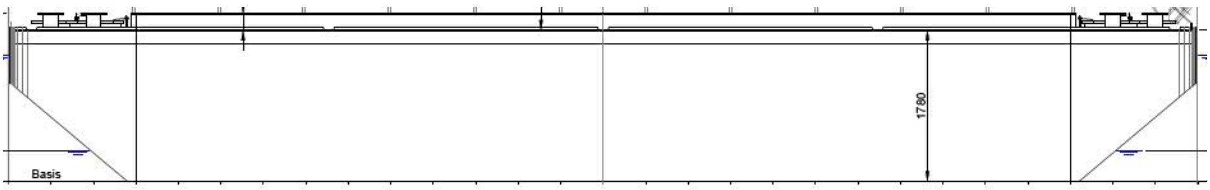


Figure 22. Kieper (17.5 ton)

D. Route Information Project Singel

KB = Kruisbaken; Rutte Groep
VV = Van Vliet; supplier of sand
NHH = Nieuwe Houthaven

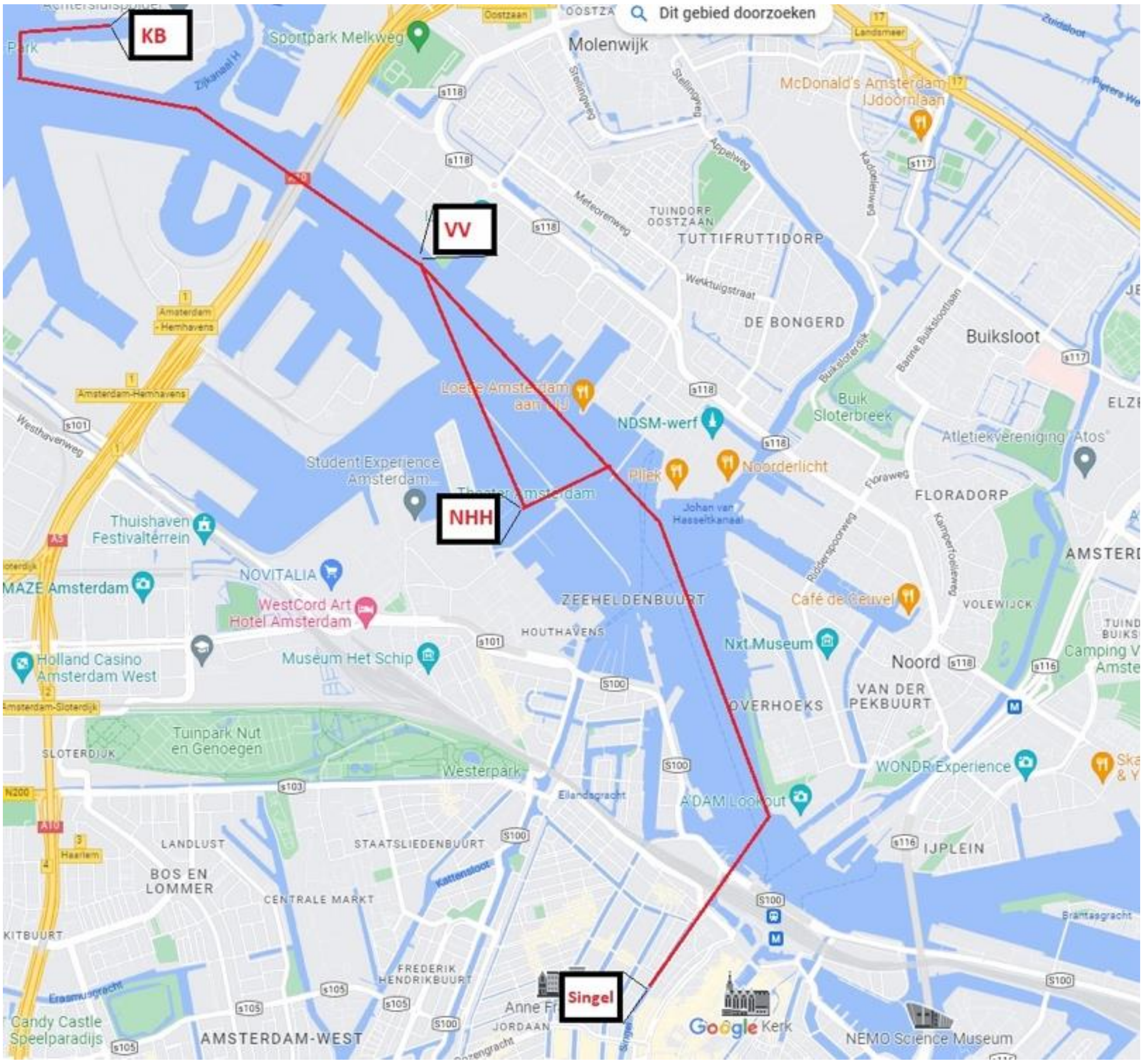


Figure 23. Representation of Routes used for Project Singel

E. Example Calculations

Example 1.

The input data:

Table 10. Input data from two transport records

Project	***Herengracht***	***Gillis***
Date	19/04/2022	19/04/2022
Origin	Hub (Pier Azie, Westelijk Havengebied)	Theemsweg 28
Destination	Herengracht	Gillis van Ledenberchstraat
Material	Damwanden	Straatkolken
Weight (kg)	19000	4284
Vehicle	Beunbak (40 m3)	Kieper
Max. Load (ton)	40	17.5
Distance (km)[7]	5.1	5.7
Calculation of unused tkm (initially)[8]	(40000-19000)*5100/(1000*1000) = 107	(17500-4284)*5700/(1000*1000) = 75

The following interventions are considered:

1. Shared Import/Export Corridor
2. Direct Exchange
3. USL buffer location
4. Cross docking (CHL)

One of the interventions that would have been possible here is cross docking. The materials from Theemsweg 28 could be transported to the hub and from there be transported together with the materials for project Herengracht. The Kieper vehicle would not need to drive into the busy city centre of Amsterdam and will be driving a shorter distance then initially. For this intervention, the distance to the origin of the Herengracht transport is 5 km. This results in a new unused tkm calculation for this transport:

$$Unused\ tkm\ (new)\ =\ (17500 - 4284) * 5000/(1000 * 1000)\ =\ 66$$

This means a reduction of 9 tkm (75 – 66) for the Gillis transport. The unused tkm value for the Herengracht transport will also be reduced since the load factor will be increased. The new value for the unused tkm is as follows:

$$Unused\ tkm\ (new)\ =\ (40000 - 19000 - 4284) * 5100/(1000 * 1000)\ =\ 85$$

This results in a reduction of 22 tkm (107 – 85) for the Herengracht transport. This intervention results in a total saving of 31 unused tkm.

[7] See Appendix F

[8] Equation 1. $unused\ tkm = (\max load - material\ weight) * distance$

F. Distances Matrix

For reference, these distances have been used for the calculations. The USL location is in the Oude Haven of Amsterdam and the CHL is the cross-docking location currently used by Beens.

Table 11. Matrix of distances between locations

A to B[m]	Singel	Herengracht	Gilles	USL	CHL
Singel	x	700	2500	2900	5400
Herengracht	700	x	1800	2600	5100
Gilles	2500	1800	x	2000	5600
USL	2900	2600	2000	x	3600
CHL	5400	5100	5600	3600	x

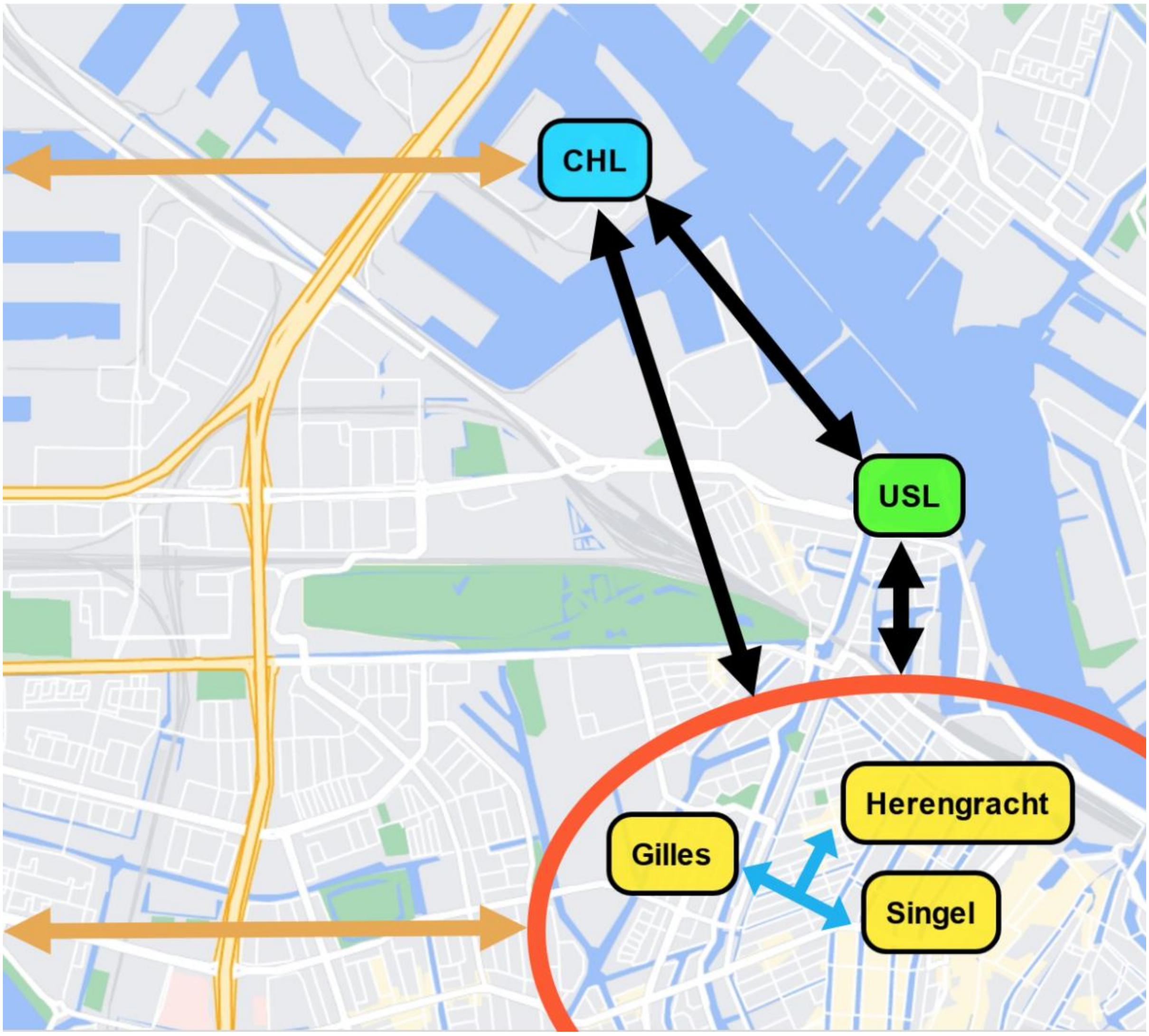


Figure 24. Indication of Project, Hub and Urban Storage Locations