Digital and Operational Advancement in Construction Logistics

A Case Study of Construction Logistics Management at BRA

Master's Thesis in Master Program Design and Construction Project Management

ALEXANDRA SÄRNSTRÖM
EDVIN WESSMAN

DEPARTMENT OF ARCHITECTURE AND CIVIL ENGINEERING
DIVISION OF CONSTRUCTION MANAGEMENT

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Alexandra Särnström
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EDVIN WESSMAN

Supervisor: Viktoria Sundquist, Department of Architecture and Civil Engineering
Examiner: Viktoria Sundquist, Department of Architecture and Civil Engineering

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Department of Architecture and Civil Engineering
Division of Construction Management
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

Cover: Materials storage area for materials in case Project A (Own picture)

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Digital och operativ utveckling inom bygglogistik
En casestudie av bygglogistikledning vid BRA
ALEXANDRA SÄRNSTRÖM
EDVIN WESSMAN
Sektionen för Arkitektur och Samhällsbyggnad
Avdelningen för Construction Management
Chalmers Tekniska Högskola

Abstract

Construction logistics management (CLM) and construction supply chain management (CSCM) are crucial for the construction industry's performance progress and potential improvement of production efficiency. Research shows that construction logistics largely affect the overall project costs and have a significant impact on environmental performance and the health and safety of both employees and civilians in urban settings. While previous research has shown clear benefits for contractors following the advancement of CLM, it is yet to provide a comprehensive understanding of how digital tools should be implemented successfully. Furthermore, there is limited research on how digital tools may alter or aid the construction logistics efficiency on the building site.

The aim of the thesis is to identify the benefits and challenges of an increased level of digitalization in construction logistics at BRA, and in doing so, provide recommendations for the use of digital tools for logistics activities in current and future projects. The aim was pursued through a case study of three ongoing construction projects at BRA with various levels in the use of digital tools for construction logistics. The study entails on-site observations and 16 semi-structured interviews with actors affected by or involved in construction logistics. An abductive research process allowed for the iterative development of theory and empirical data, which was analyzed using an analytical framework.

The study shows that well-functioning construction logistics can contribute to monetary gains and improved production performance. However, these values are difficult to measure and are therefore often overlooked by practitioners who tend to focus on the challenges of implementing and maintaining CLM and CSCM instead. These challenges generally boil down to organizational preconditions and work culture in the construction industry, as well as the limited knowledge and competence within construction logistics.

In conclusion, early involvement of construction logistics planning facilitates the implementation of digital tools in production. In every project, BRA should assign explicit responsibility for construction logistics to a specific person or team and utilize digital delivery management systems to increase coordination between actors on site and suppliers and decrease the frequency of unplanned events. Task distribution tools should be utilized in projects with dedicated logistics workers, as they provide a better overview, allowing more accurate in-depth planning and reducing collisions in the schedule during the production phase. To promote the advancement of construction logistics management in the early phases of the construction process, BRA needs to consider the project-specific preconditions and plan the logistics activities thereafter. Lastly, the study concludes that evaluation methods are needed to identify the extent of indirect and intangible benefits that digital tools for construction logistics can bring.

Keywords: construction logistics, construction logistics management, construction industry, supply chain management, digitalization, digital tools.

Sammanfattning

Ledning och styrning av bygglogistik och hantering av byggförsörjningskedjan är avgörande för byggbranschens prestandaframsteg och potentiella förbättringar av produktionseffektiviteten. Forskning visar att bygglogistiken i hög grad påverkar de totala projektkostnaderna och har en betydande inverkan på miljöpåverkan, samt hälsa och säkerhet för både anställda och civila i urbana miljöer. Även om tidigare forskning har visat att det finns tydliga fördelar för entreprenörer med en utveckling inom bygglogistik, har den ännu inte gett en heltäckande förståelse för hur digitala verktyg ska implementeras på ett framgångsrikt sätt. Dessutom är forskningen begränsad angående hur digitala verktyg kan förändra eller stödja bygglogistikens effektivitet på byggarbetsplatsen.

Syftet med detta examensarbete är att identifiera fördelarna och utmaningarna med en ökad nivå av digitalisering för bygglogistik hos entreprenörsföretaget BRA, och därvid ge rekommendationer för användning av digitala verktyg för logistikaktiviteter i pågående och framtida projekt. Syftet uppnåddes genom en fallstudie av tre pågående byggprojekt med olika nivåer i användande av digitala verktyg för bygglogistik. Studien innefattar observationer på byggplatserna och 16 semistrukturerade intervjuer med aktörer som berörs av eller är involverade i bygglogistik. En abduktiv forskningsprocess möjliggjorde iterativ utveckling av teori och empirisk data, som sedan analyserades med hjälp av ett analytiskt ramverk.

Studien visar att en väl fungerande bygglogistik kan bidra till ekonomiska vinster och förbättrad produktionsprestanda. Dessa värden är dock svåra att mäta och förbises därför ofta av aktörer som tenderar att fokusera på utmaningarna med att implementera och upprätthålla ledning av bygglogistik och byggförsörjningskedjan istället. Dessa utmaningar bottnar generellt i organisatoriska förutsättningar och arbetskulturer inom byggbranschen, samt en begränsad kunskap och kompetens inom bygglogistik. De mest märkbara fördelarna med att utveckla bygglogistiken visade sig ofta relatera till mjukare värden så som en förbättrad arbetsmiljö.

Sammanfattningsvis underlättar en tidig introduktion av bygglogistikplanering implementering av digitala verktyg i produktion. I varje projekt bör BRA tilldela ansvaret för bygglogistiken till en specifik person eller grupp, samt nyttja digitala system för leveransplanering för att öka samordningen mellan aktörer på byggplatsen och minska frekvensen av oförutsedda händelser. Digitala verktyg för uppgiftsfördelning bör nyttjas i projekt som använder logistikarbetare då de ger en bättre överblick, vilket möjliggör en mer djupgående planering och minskar kollisioner i schemat under produktionsfasen. För att främja utvecklingen av bygglogistik i de tidiga faserna av byggprocessen behöver BRA ta hänsyn till projektmässiga förutsättningar och planera logistikaktiviteterna därefter. Slutligen drar studien slutsatsen att det behövs utvärderingsmetoder för att identifiera omfattningen av indirekta och immateriella fördelar som digitala verktyg för bygglogistik kan ge.

Nyckelord: bygglogistik, ledning av bygglogistik, byggindustrin, hantering av byggförsörjningskedjan, digitalisering, digitala verktyg,

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Another huge thank you to everyone participating in the interviews. Your experiences are the very backbone of this study and have brought a lot of interesting insights into the construction industry and the improvement potential that the future holds.

Finally, we want to thank our opponent Viktor Wassén for valuable criticism, and Magnus Gustaver who coded this thesis template in 2020. It has saved us a lot of effort in writing this report.

Alexandra Särnström & Edvin Wessman, Gothenburg, June 2023

Contents

List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

BIM	Building Information Modelling
CAD	Computer-aided Design
CCC	Construction Consolidation Center
CLM	Construction Logistics Management
CLP	Construction Logistics Plan
CSCM	Construction Supply Chain Management
DMS	Delivery Management System
GTA	Gross Total Area
ICSCL	Integrated Construction Supply Chain Logistics
JIT	Just-in-time
LC	Lean Construction
LM	Lean Management
RFID	Radio Frequency IDentification
SCM	Supply Chain Management
TPL	Third Party Logistics
WAP	Work Allocation Plan

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1

Introduction

This chapter provides a theoretical background to logistics management within the construction industry and its impact on productivity at the production stage. It continues by positioning digitalization in the industry within logistic processes to motivate why the research questions and aim of this thesis are relevant, along with a brief description of the company BRA for which the study is conducted. Finally, the aim as well as the limitations of the study are presented.

1.1 The importance of digital tools and operational improvement in construction logistics

Logistics management is commonly included within the concept of supply chain management (SCM) and plays a crucial role in construction production as it affects costs that have a big influence over the project's overall outcome such as inventory costs and transportation costs (Civic, 2018). According to Sullivan et al. (2011), the main goal of the logistics management process is to deliver exactly what the client desires within the agreed time frame and budget, with the promised quality. The importance of well-planned logistics in construction is further emphasized by Dubois et al. (2019), as they state that planning the logistics and transport can reduce as much as 20% of the total construction costs. Although this is the case, Civic (2018) declares that there currently is a lack of awareness regarding the need for enhanced logistics flows within the construction industry. One of the reasons behind this is the limited knowledge and uncertainty about potential benefits due to a lack of information concerning new digital technologies and innovations in construction logistics. Without a proper understanding of possible effects in terms of costs or societal and environmental health, it is exceedingly difficult for decision-makers to know what is required to make construction logistics more efficient.

The main cause for budget overruns in construction projects is supply-chain-related aspects such as resource scarcity and variations in the costs of materials and equipment. Inefficient construction logistics have frequently been described in the literature as a barrier to better performance (Janné & Rudberg, 2017) and Koskela & Vrijhoef (2000) states that construction supply chains commonly entail wasteful activities and issues with productivity due to poor supply chain management (SCM).

To illustrate the scale of these issues, Thunberg & Persson (2014) found less than 40% of all deliveries to construction sites arrived with the correct quantities, on time, at the correct location, and undamaged. At present, the challenges of efficiently maintaining the supply chain and the logistics onsite generate unnecessary transport and low delivery performance. This consequently advances to shortages of materials and resources, which ultimately results in delays in production or a need for ad hoc express transport. Insufficient logistics management on site causes material losses and costs, as well as increased generated waste and hazards for onsite workers (Civic, 2018).

Digitalization has been highlighted as a way to provide more efficient construction logistics in order to improve project performance (Whitlock, Abanda, Manjia, Pettang, & Nkeng, 2018). How the efficiency of construction logistics can be increased through digitalization is not yet thoroughly researched, Yevu et al. (2021) argue. According to Persson & Thunberg (2013), utilization of new technologies can prevent cost overruns. Already, there is a wide range of digital tools relating to supply chain and logistics within the construction sector. In Sweden, two of the most widespread digital systems within the industry, *Lognet* and *Myloc*, have gained attention in the last couple of years. Both tools aim to simplify logistic management on the production site and enable collaboration between all suppliers for a project through sharing of logistic elements such as planning, estimated delivery times, and call-offs. The tools aid information sharing between the suppliers and the contractor, resulting in less administration for the contractor and more control through increased traceability (Sandlund, n.d.). In addition, LogNet offers functions such as CO_2-calculations of all transportation to the work site, statistics foresight, and accuracy of delivery (Bygglogistik, n.d.). However, Sullivan et al. (2011) state that contractors seldom invest capital in logistic improvement, partly because construction projects generally are not capital-intensive. The willingness of the contractors is constrained by conflicting goals and values between involved parties, and in order to achieve the lowest costs possible, logistics costs often are kept to a minimum by avoiding spending time and monetary investments in that discipline (Civic, 2018). In addition to this, there is little comprehensive research on the integration of such technologies with Building Information Modeling (BIM), the connection between existing and emerging technologies, and their impact on sustainability (Yevu et al., 2021). These gaps in knowledge contribute to the challenges of digital implementation that the construction industry faces. Therefore, digital investments in construction logistics are yet to be established as best practices.

1.1.1 Construction logistics' contribution to improved environmental sustainability

Research shows there is potential for improving construction logistics. The potential for improved productivity, cost efficiency, time, and quality through digitalization is of high importance for practitioners within the industry. These improvements would lead to less transport to and from the building site as well as less material waste. Some studies argue that the effects on environmental and social sustainability from improved logistics are even more pressing matters. Guerlain et al. (2019) for example, claim that as much as 30 % of urban heavy vehicle transport is related to construction. This diesel-powered transport that pollutes dense cities is expected to increase in numbers as more people move to urban areas. The United Nations (UN, 2019) projects that the world´s rural population is close to its peak, while the urban populations will continue to grow rapidly. By 2050, the projections estimate the global urban population to have increased from 55% to 68%, and this figure will be even higher in the high-income northern European countries. In Sweden, the urban share of the population is projected to reach 93% by 2050. This means that a vast amount of urban construction will commence in the near future, in cities that become denser and larger in size. Total emissions from the urban transport of materials will rise, and they will have a direct impact on more people through air, noise, and water pollution. Moreover, increasing amounts of heavy traffic have implications for safety. Construction projects located in dense urban areas need to coexist with the public, and their heavy vehicles and machinery have to mix with commuters and pedestrians which poses risks for accidents near and around the sites. Additionally, the working environment within the perimeters of construction sites is by far the deadliest among industries in Sweden, and the primary cause of deadly accidents at work is vehicle and machinery related, according to the Swedish Work Environment Authority (2022).

It is therefore important to reduce the number of transport vehicles to construction sites as much as possible, both from sustainability and safety perspectives. Furthermore, keeping track of and lowering the costs through more efficient logistics is in every contractor´s and client's best interest. This requires significant planning and the appropriate tools for monitoring and controlling logistic activities in and around the site. Digitalization is a major cause of transformation throughout society and across industries, and presents major possibilities for value creation (Parida, 2018). Previous research shows that the construction industry is yet to fully reap these benefits. A higher degree of digitalization in logistics management could lead to major positive transformations, and potentially present new risks. Therefore, it is vital to study the phenomena of digitalization in construction logistics, to provide guidance for the way forward.

1.2 BRA

In order to study digitalization in relation to construction logistics, the study covers ongoing projects at the company BRA (Billström Reimer Andersson AB) in the Gothenburg region. The study is conducted in cooperation with the company and aims to provide results that contribute to their business strategy and produce useful recommendations for the company.

BRA is a fast-growing Swedish contracting company founded in 2007, and its majority owner is Veidekke, the fourth-largest construction company in Scandinavia. They currently have around 400 employees and an annual turnover of around 4 BSEK. Their project portfolio is primarily focused on the construction of commercial and residential buildings for private clients, but they also do property development projects, facility management, infrastructure, and groundworks. Most of their projects are situated in and around Gothenburg and Stockholm.

In their different construction projects, BRA has adopted various levels of advancement in their working methods and logistics solutions. Some of the larger projects have dedicated logistics staff, whereas others have more complex supply chain management systems and others incorporate logistics activities in the job description of foremen and site managers. The projects have one, none, or several digital solutions in place, and the logistic activities may require different levels of digitalization to provide optimization in terms of cost and quality. This variation in the sophistication of logistics working methods makes them a suitable company for studying different levels of digital advancement in logistics across projects.

1.3 Aim

The aim of the thesis is to identify the benefits and challenges of an increased level of digitalization in construction logistics at the company BRA, and in doing so, provide recommendations for the use of digital tools for logistics activities in current and future projects. This will be done by answering the following research questions:

RQ1: What are the benefits and challenges associated with the advancement of construction logistics management strategy in general?

RQ2: How can the implementation of digital tools contribute to a potential reduction of construction logistics costs?

RQ3: How can the implementation of digital tools within construction logistics contribute to improved sustainability?

RQ4: Which project features are key in the suggestion of various levels of digital advancement for construction logistics?

1.4 Limitations

This study was conducted over a limited period of time (from January 2023 to May 2023). This was a deliberate choice due to the nature of a master-level thesis, and the opportunity provided by the company. A longer study, following several projects over their entire life duration, may have reached more comprehensive and nuanced conclusions.

The focus of our study is on the production phase of the construction process. We find it interesting to focus on the tangible effects on site, as it is where major issues arise. Through explaining the practices of construction logistics in relation to production, as well as identifying potential gains in terms of costs, quality, and time, we hope to inspire new and altered behaviors that have direct effects on the final product.

The geographic limitations of our study will be the Swedish construction context, with a focus on projects in and around Gothenburg. This area is interesting from a research perspective since practitioners have projected major densification and influx of residents to the area in the near future (Göteborgs Stad, 2022). Construction logistics will be an important key to the future development of the area and the logistical challenges will increase in complexity and scale as future construction commence.

1.5 Structure of the thesis

The thesis is structured as follows. The problem formulation of logistical advancement and the use of an increased level of digitalization is introduced in the first chapter along with the aim of the study and elaborated further through the theoretical framework in chapter two. Thereafter, the methodology of our research is presented and reflected upon in chapter three. In the fourth chapter, the results of our empirical study are brought forward, providing findings to be analyzed in relation to the theory in chapter five, discussion. Lastly, chapter six contains the conclusions of the study and gives recommendations for BRA. The structure of the report is presented in Figure 1.1 below, which shows the contents and connections between the different chapters.

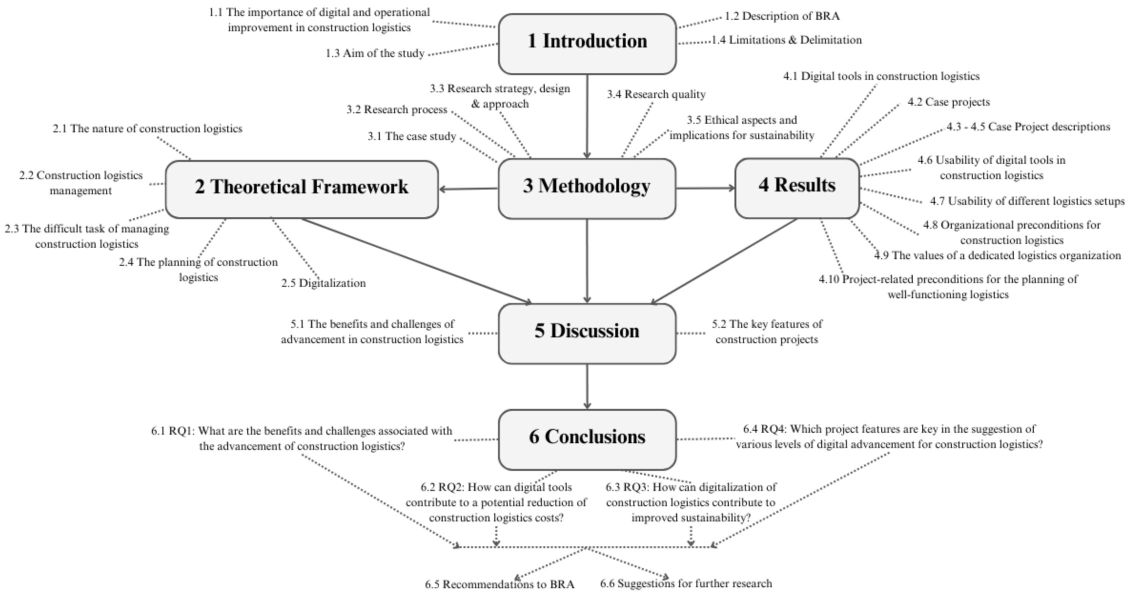

Figure 1.1: The structure of the chapters included in the thesis.

2

Theoretical Framework

This chapter presents the theoretical framework, which provides knowledge in relation to the phenomenon of logistics management in construction in general and digitalization specifically. In this chapter previous research within the following areas will be presented; logistics management within the construction sector, digitalization of construction logistics, as well as documented benefits and challenges related to digital tools in construction logistics. In addition, an analytic framework for the thesis will be displayed at the end of this section, showcasing the relationship between the research questions and the concepts brought up in the report, as well as how they affect each other.

2.1 The nature of construction logistics

Within the construction sector, logistics management involves the planning of cost-effective storage, transportation, handling, distribution of materials, and synchronization of involved parties. In addition to this, construction logistics concern all shipments of equipment, staff, and disposed materials to and from the construction site (Civic, 2018). Logistics first became a discipline within the construction process during the 1980s in the United Kingdom as it developed with the advent of construction management (Sullivan et al., 2011). Back then, construction management involved the procurement of specialist trade contractors, while still hiring a project management contractor who would coordinate and manage the different disciplines within the construction process. The specialist trade contractors would manage non-core activities such as site welfare, housekeeping, security, access, and traffic, and some clients began to realize the value of having specific staff assigned to these types of responsibilities, which lead to the emergence of specialist logistics contractors.

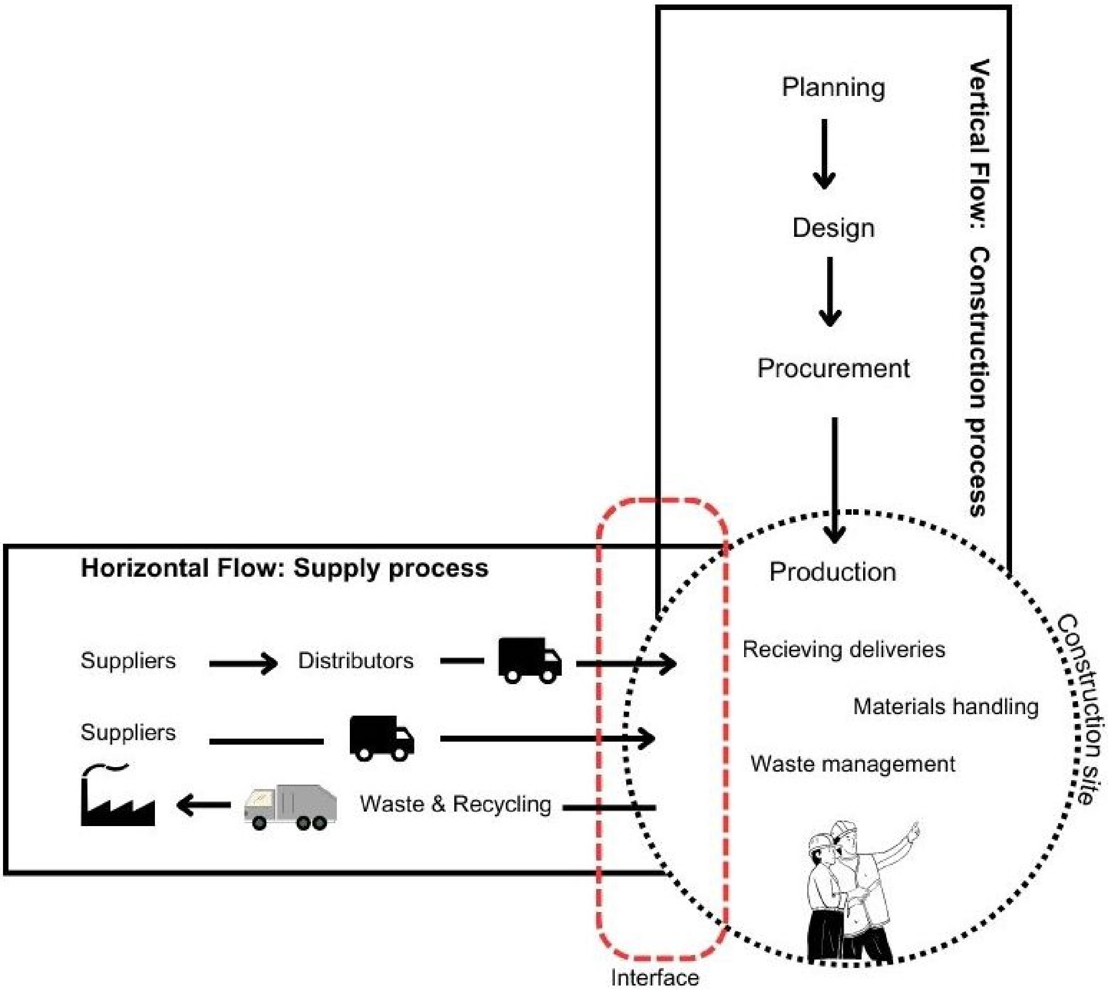

Figure 2.1: The actors involved influencing the project outcome. (Based on the model presented by Sezer & Fredriksson (2021a)).

In Figure 2.1 it is shown that the decisions made by actors involved in the planning, design, and procurement phases of the construction process have an impact on how the production process will be planned and conducted. Together, onsite and off-site logistics affect the material flow and workflow within the production, creating the foundation for productivity within the building phase. In order to clarify the coherence between the involved functions, one can view the supply process as a *horizontal process flow*, and the construction process as a *vertical process flow*.

The vertical process flow surrounds activities and actors involved in the construction process, from the initiation and planning phase until the end of the project. Each decision made before and during the production phase has an effect on the construction and overall outcome of the product, which influences the conditions and requirements for construction logistics management (CLM). The actors involved in the vertical process flow are generally the project manager, client, architect, and engineers. Depending on variables such as the design of the building or the shape of the environment, other actors may be included. When the contractors have been procured and the production phase has been initiated, subcontractors enter the vertical process flow as well. The horizontal process flow is primarily constituted by the obtaining of material for the construction, which is of utmost importance for the success of the project and influences the production line every day. The horizontal flows are connected to the construction supply chain management (CSCM) through the managing of inter-organizational relationships with suppliers, and involved actors in these process flows can be the suppliers, manufacturers, distributors, and waste managers. The type of contract prevailing in the project has an effect on the circumstances the contractors will have to develop the CLM and CSCM during the production and the demands they can make on their subcontractors, suppliers, and distributors.

2.2 Construction Logistics Management

Construction logistics management (CLM) is identified as a major part of the construction process and should be managed by the construction industry (Guerlain et al., 2019). Within construction, logistics involve the planning and organization, coordination and governing of material flows (Agapiou, Clausen, Flanagan, Norman, & Notman, 1998). This applies from the extraction of the raw material to the assembly of the new building or component. In construction, logistics management refers to the handling and outlining of strategic planning, transportation, and distribution of resources. According to Sullivan et al. (2011) CLM also contains the handling of the communication between relevant actors and suppliers, onsite security, coordination of infrastructure, waste management, and good housekeeping. It is stated by Agapiou et al. (1998) that the activity of supplying building materials is filled with obstacles, which can impact the project's productivity. According to Janné & Fredriksson (2022), it is required that construction projects invest in CLM in order to reduce logistics-related impacts on site. However, this should be done without interfering with the efficiency of the production.

Construction logistics can be separated into two primary subcategories that describe the included functions (Sezer & Fredriksson, 2021a): *off-site logistics* and *onsite logistics*. In Figure 2.2, the relationships between the functions included in construction logistics are presented.

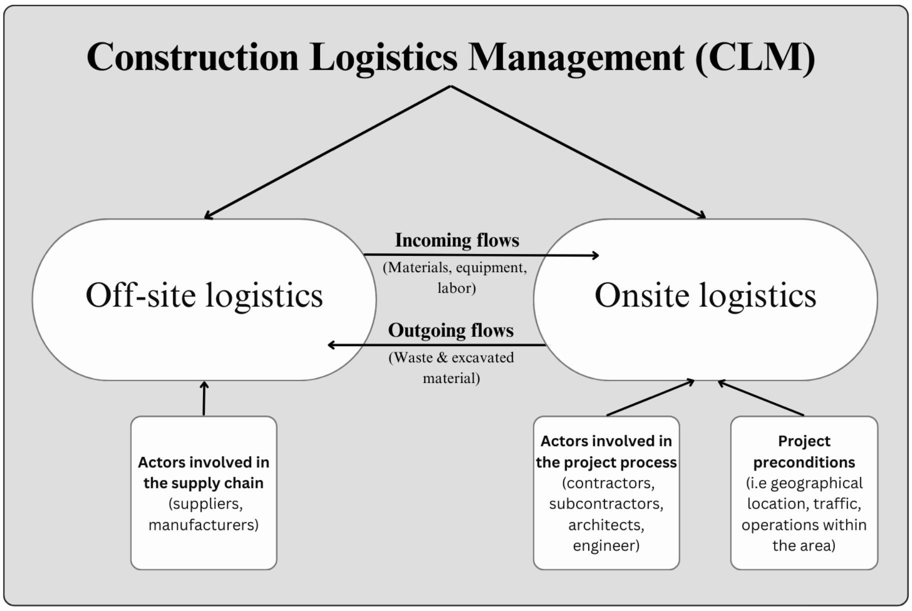

Figure 2.2: An overview of CLM and onsite and off-site logistics.

The first subcategory is onsite logistics, which contains the management of the logistics on the construction site, such as delivery control, inbound transport, removing materials, etc. When planning the onsite logistics, variables such as geographical location, type of environment (urban or rural), traffic, shared roads, and ongoing operations within the area need to be considered (Agapiou et al., 1998).

The second sub-category is off-site logistics. This is a term that implies the manufacturing, transportation, and distribution of materials and resources. Off-site logistics compose the major incoming and outgoing flows. Sezer & Fredriksson (2021a) emphasize that most housebuilding projects, regardless of project type, have the same basic flow patterns in each phase of construction. Throughout the lifecycle of a project, these flows will vary in size according to a storage pattern and require different modes of transport. According to the authors, the three main incoming flows are materials, equipment, and labor. The outgoing flows of the construction site mainly concern the transportation of waste and excavated ground materials. In order to achieve well-functioning incoming and outgoing flows, the contractor needs to implement CLM.

2.2.1 Construction supply chain management

When CLM is mentioned within the literature, construction supply-chain management (CSCM) is a frequently occurring term. According to Koskela & Vrijhoef (2000), CSCM is defined as a "network of organizations that are involved through upstream and downstream linkages [...]", and considers the entire organization of the multiple relationships between involved suppliers, manufacturers, and other actors in order to increase the alignment, transparency, and coordination of the supply chain. A supply chain contains three or more companies that are directly linked to each other (Larson & Halldorsson, 2004). However, an extended supply chain, which is more representative of the construction supply chain, includes "suppliers of the immediate suppliers and customers of the immediate customer". The up and downstream flows involve all actors and go from the initial supplier to the ultimate customer. It is described by Janné & Rudberg (2017) that the basic concept behind supply chain management (SCM) is that individual companies – the contractors in the construction sector – do not compete on the market as independent entities but rather as units interlinked with their suppliers and clients.

Although CSCM is a crucial aspect to achieve efficient material- and workflows, Koskela & Vrijhoef (2000) point out a lack of basic SCM within the construction industry. Issues and waste streams generated within the construction supply chain are very common, which can be expected if the control of the supply chain of a project is short-sighted and out of date (Koskela & Vrijhoef, 2000). Often the results of these problems become evident in later stages, such as on the production site. According to Larson & Halldorsson (2004), one reason for this might be that there is no coherently agreed, well-defined understanding of what SCM actually implies. Not only does this lead to confusion but makes SCM exceedingly difficult for organizations to implement. One contributing factor to the lack of definition of SCM is the differing opinions on how SCM is related to logistics. Larson & Halldorson highlight four unique perspectives on the relationship between logistics and SCM that are generally recognized (see Figure 2.3 below):

- *Traditionalists* choose to position SCM within logistics, implying that SCM is a small part or special type of logistics, such as external or inter-organizational logistics (Larson & Halldorsson, 2004).

- *Relabelling* is the perspective that renames logistics to SCM and uses SCM and logistics network as synonymous terms. Backing this perspective is Janné & Rudberg (2017), who state that the terms CLM and CSCM essentially are used to describe the same approach of holistic and systematic handling of material and resource flows.

- *Unionists* contradict traditionalists and believe that logistics is a part of SCM. According to this perspective, SCM includes logistics, strategic planning, marketing, information technology, and sales (Larson & Halldorsson, 2004). Westland (2019) agrees with this view as he claims that CLM is a subgroup of the larger CSCM, which entails the planning and control of efficient flows involving storage, services, and goods from the point of origin to the point of consumption.

- *Inter-sectionists* believe SCM to be a broad strategy that intersects with logistics as the strategic integrative element. Larson & Halldorsson (2004) exemplify this with purchasing. Within the purchasing area, negotiation is the strategic, or "tactic" element and would be handled by the supply chain manager.

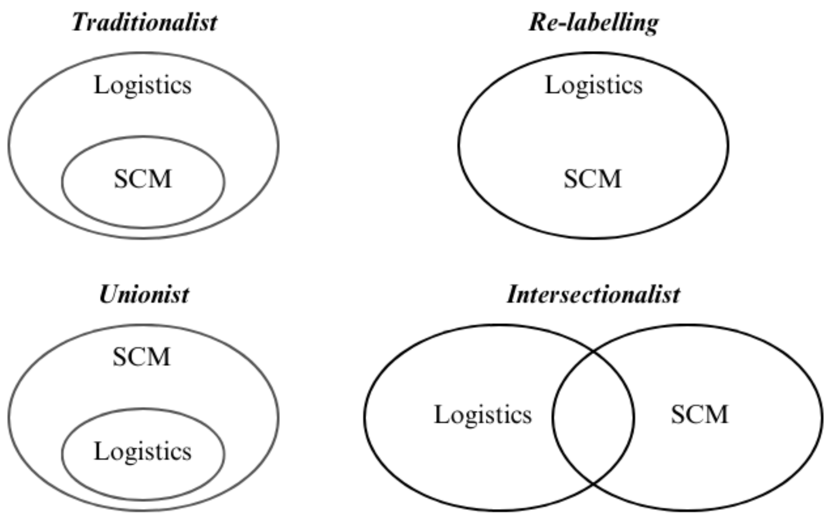

Figure 2.3: The different perspectives of SCM (Larson & Halldorsson, 2004).

Logistics practitioners must find a common definition of SCM with clear boundaries in regard to CLM (Larson & Halldorsson, 2004). Each of the perspectives above brings its own interpretation of what SCM implies, which according to the authors drastically affects the way organizations choose to implement SCM. While *Relabellers* simply can adjust their vocabulary and change the term 'logistics' to 'supply chain management, *Unionists* require more comprehensive work. They will have to organize an SCM line and change many relationships within the company, which most likely will be met with some resistance. As all supply chain participants must agree to the implementation of SCM, one must also consider their perspective on SCM versus logistics, which is why it is important to understand and know these perspectives.

In their study, Larson & Halldorson (2004) found that conflict management of cross-functional and inter-organizational relationships generally are highly related to SCM by logistics educators together with strategic purchasing, which includes early supplier involvement and procurement. Jenkins (2022) claims that CSCM involves more comprehensive planning, which covers all coordination between involved parties, while logistics mainly revolves around the movement and storage of items within the supply chain. This claim was backed up by Larson & Halldorson (2004) as their study showed that warehousing, transportation, and facility location are highly regarded to fall under the CLM category. According to Westland (2019), logistics mainly focuses on the inbound planning and control of internal functions and external flows such as inventory management, purchasing, transportation, and warehousing. The aim behind the logistics management process is to deliver exactly what the client desires within the agreed time frame and budget at the promised quality (Sullivan et al., 2011).

2.3 The difficult task of managing construction logistics

According to (Sullivan et al., 2011), there are several characterizing factors that influence logistics management in the construction industry. The most essential influence is due to four important elements that always occur within construction production:

- The *temporality* of the projects. Each new project can be compared to a temporary organization where each time a project is launched, new kinds of relationships between contractors, suppliers, and clients are formed (Janné & Rudberg, 2017). Since the location is unique, a new logistic setup is required for each project (Civic, 2018).

- The *material intensity* of the projects and the requirement for irregular supplies further complicate logistics management within construction compared to other industries. Depending on the stage of the project, different types of materials will be needed to be supplied on a variating basis.

- The *highly sensitive activity chain* is a factor that impacts logistics planning highly. Activities must be completed in sequence. If one activity is delayed, the following activities will be affected, and the supply of materials is required to be replanned accordingly (Civic, 2018).

- The *fragmented nature* of construction projects is often mentioned in literature as a key characteristic of the industry. Decisions are made locally within the projects, resulting in different working and data management methods.

According to Civic (2018), these elements make the governing of logistics within construction projects particularly difficult, which has contributed to the fact that the construction industry generally has been slow to recognize the benefits of using professionals and strategies committed to only logistics (Sullivan et al., 2011). The issue with this is the fact that the industry is losing out on opportunities for further improvement. Construction logistics have long been synonymous with ad hoc transport and solutions in the industry (Fredriksson et al., 2022). By solving logistical issues as they arise, the projects miss out on systematic benefits that early involvement of logistics actors and planning has been shown to produce. Fredriksson et al. (2022) argue that the only way this mindset will change is if all actors who are in a position to place relevant demands start doing so. According to Sullivan et al. (2011), other industries have recorded an improved working capital of 20% after investing in smart logistics. Monetary increases of this size would decrease cost overruns in construction projects. In terms of time efficiency, it is mentioned that as much as 60-80% of the total executed work in a project involves purchases regarding materials and services from suppliers and subcontractors, further proving the SCM's influence on the project's performance (Ekeskär & Rudberg, 2022).

2.3.1 The issues with traditional construction logistics management

Traditionally, companies would ensure good workflows in the production phase by holding considerable stockpiles of materials. This method has been shown to be unfavorable both in terms of finances and space management on-site and has become practically obsolete in the present-day production phase. However, traditional management methods still remain, and the most common supply and site logistics setup is what (Dubois et al., 2019) describes as the 'decentralized coordinated configuration', where transports to the site usually happen through one of two typical scenarios:

- The first is *next-day deliveries* which prompt a lot of ad-hoc orders, resulting in low fill rates of delivery vehicles and subsequently a large number of vehicle arrivals on site. This is common in many small-scale projects when suppliers offer free deliveries and generous call-off windows of time.
- The second is the *over-filling of delivery vehicles,* which is when suppliers offer discounts for large volume orders and deliver with full trucks.

This can result in unnecessary material stock on site, increasing the risk of material damage and loss. Both scenarios are sub-optimal for the production on-site and contribute to the inefficiency of delivery planning (Dubois et al., 2019). Sezer and Fredriksson (2020) produced a pioneering study on transport impact from construction sites. By compiling data from delivery planning systems and gate passages of 13 different projects in Stockholm, they were able to find a correlation between the gross area of constructed buildings and the number of transports to the site in different stages of construction. On average, 0,57 transports per constructed square meter can be expected according to the study. By dividing the projects into quartiles of their life cycles (site preparation and groundworks, framing and remaining groundworks, installations and interior, remaining installations and interior), they found that the number of transports peaks significantly around the middle of the project´s completion. The following year Sezer and Fredriksson (2021a) did a follow-up study with a larger sample size of 40 projects and found a similar average of 0,49 transports/ sqm. Furthermore, they found that complex projects, meaning projects that combine more than two different types of projects (housing, offices, parking, kindergartens, etc.), have fewer transports/sqm than the average. The average CO_2 emissions per sqm were 16,6 kg, but complex projects achieved lower numbers in this discipline as well.

In the study, Sezer and Fredriksson (2021b) identified additional significant patterns. As many as 50% of deliveries arrived before 09:00 in the morning, and very few deliveries happened on weekends. This shows that even in projects that use booking calendars for deliveries and thereby have the ability to control delivery times to minimize interference with production efficiency, actors choose to act traditionally instead. The opportunity to avoid congestion both in the city and on-site, as well as for the suppliers to schedule more efficiently seems to be overlooked in general.

According to Kong (2018), traffic congestion in particular contributes considerably to the environmental impacts of a construction project. During a study made by the Transport Development Research Center in Beijing, it was found that traffic congestion can cause up to an additional 16,700 tons of CO_2 and 9,5 tons of other pollutants daily in the city. For context, it was estimated by Wang, Chen, & Fujiyama (2015), that the urban passenger car transport in Beijing generated about 11,300 tons of CO_2 daily in 2012, implying an additional 147,8% of CO_2-emissions per day from congestion alone.

2.4 The planning of construction logistics

Whitlock et al. (2018) propagate the use of a construction logistics plan (CLP) as a base for developing efficient logistics in a project. Such a plan is ideally requested by the client and produced by the main contractor at the design stage, or even before the signing of the contract. A good CLP can greatly impact the efficiency of the logistics and in turn the number of deliveries and transports around the site. Yet, the authors claim that it is yet to be established as a common practice to outline the preferred logistics practices in such a document before the construction commences. The CLP should provide a holistic view of all relevant aspects of logistics on and off-site, guiding the actors involved throughout the project. Key elements of a well-written CLP according to the article include:

- An overview of the project, detailing the general information about the location, the construction process, and the conditions of the site.
- A brief overview of the supply chain, including the main in and outflows of materials and means of transport.
- Detailed planning of the supply chain. Here, most of the key elements of logistics are outlined to serve as guiding principles for both contractors and suppliers. This involves the planning of off-site logistics such as transport routes and co-planning with adjacent sites to reduce the traffic pressure on access roads. Safety concerns regarding transport should be accounted for, as well as potential bottlenecks due to turning radius along nearby access roads, pedestrian interference, or the possibility of waiting areas for vehicles. If the project will utilize prefabricated elements, construction consolidation centers (CCCs), or checkpoints, the details of such an arrangement should be defined.
- Site disposition plans and on-site arrangements. These should describe unloading zones, gate access, crane locations, and internal vehicle and pedestrian routes within the site perimeters. Additionally, storage zones for materials and equipment as well as elevators and staff facilities.

The CLP document is a crucial tool for the management in charge of logistics as production is initiated. The continuous, iterative process of refining and optimizing the logistics will then be based on the preconditions established by the CLP. The next step is to establish the techniques to be used, and to what extent digital systems can aid in the achievement of well-functioning logistics both on and off-site.

2.4.1 Just-in-time

Just-in-time (JIT) is a strategy for supply chain management and is included in lean construction (LC), which has developed as a sub-branch of lean manufacturing (LM) (Kifokeris, 2021). LM was initially introduced by Taichi Ohno, who came to develop the process to streamline production within the automotive industry (Ballard & Howell, 1995). Ohno's main goal was to change the process of producing for an estimated demand to producing for actual demand and by doing so, eliminate waste (activities that do not create value) along the production line.

In the construction industry, JIT involves the deliverance of materials and resources in the correct quantity right before they are needed for activity and is intended to increase planning efficiency and contribute to productivity (Kifokeris, 2021). Lately, the method has grown in usage, especially in urban projects with limited space, due to increased focus on impacts following larger and longer deliveries to the building site such as traffic congestion, environmental pollution, and more stored material on site (Kong et al., 2018). Furthermore, it is stated by Sullivan et al. (2011) that some global logistics firms predict that contractors could achieve a reduction in labor costs and materials by circa 15% when using just-in-time (JIT) on the building site.

A prime example of materials that require JIT delivery is ready-mixed concrete, which must be poured before settling (Designing Buildings, 2021). Another example is precast elements, which are created within controlled environmental conditions and only require assembly on site (Kong et al., 2018). However, the extent of complexity accompanying each construction project along with pressures from leading, relevant actors to keep costs and time down often results in uncertainties regarding the actual benefits of JIT (Ballard & Howell, 1995). Using JIT as a delivery method involves an increased risk, as delays potentially can stop workflows within the production. However, it is stated by Kifokeris (2021) that JIT as a part of LC has the potential of contributing to more productive project deliveries with enhanced cooperation throughout the production phase.

2.4.2 Third-party logistics

As earlier mentioned, the use of specialized professionals dedicated to only logistics is verified to improve the efficiency of the supply chain. One approach to logistics management is third-party logistics solutions (TPL), which has become a growing trend within the industry, according to Janné & Rudberg (2017). In their conference paper 'Costs and benefits of logistics solutions in construction', TPL essentially is explained as an external organization that handles all or part of a company's logistics activities. The services provided by TPL are based on previously arranged formal contractual relations and can be commenced by either external or internal influences. At present day, the setup of TPL typically is focused on the management of logistics and materials on site, activities which traditionally were handled by the contractor (Ekeskär & Rudberg, 2022). This becomes especially helpful for the contractor during large projects in urban areas, where space is limited, and temporary unloading of materials should be avoided. However, there are TPL providers who also offer other services such as digital logistics tools, deliveries to the construction site, machinery for unloading, and control of traffic.

The results of an analysis performed by Ekeskär & Rudberg (2022) indicated that TPL has the possibility of functioning as a systems integrator by creating balance in the supply chain and coordinating the supply chain with the construction site. By outsourcing the logistics, the contractors create opportunities to liberate resources and focus on their core activities. According to Janné & Rudberg (2017), this increases the value adding time to the project. However, the authors also mention some of the concerns raised by contractors regarding TPL setups. Their concerns included fear or worry about loss of control, loss of in-house capabilities and knowledge, high fees, or incompetence of the TPL provider (Ekeskär & Rudberg, 2022). By studying other industries, it is concluded that TPL implementation requires time and dedication for contractors to reap its full potential.

2.5 Important logistics configurations

Dubois et al.(2019) describe three distinct modes of organizing logistics in construction, all of which have impacts on the involved actors in different ways.

The first mode is the earlier mentioned *De-centralized coordinated configuration.* This is the most traditional approach to the organization of logistics in a construction project. It entails minimal cooperation and coordination between on and off-site logistics, leaving each contractor to handle their own supply chains. On-site materials handling is carried out by construction workers, regularly disrupting their primary work. Suppliers plan their deliveries without any demands from or consideration for the conditions on-site.

The second mode, the *On-site coordinated configuration*, is more sophisticated than the first one and common in large, complex projects. Here, there is a joint effort of coordinating the interface of the supply chain and the construction site. While being more challenging for the suppliers as they now have to adapt to the routines of the site, it provides more control for the logistics management on site. In this configuration, the responsibility of coordination is typically carried by a logistics manager and sometimes their team, either from the main contractor or an external logistics specialist firm. This person or team handles all of the on-site logistics planning. Dedicated material distribution staff handle material movements within the site area, from the unloading zone to the point of installation, leaving the construction workers to focus all of their time on their primary tasks.

The last mode of organizing construction logistics as described by Dubois (2019) is *the Supply network coordinated configuration.* This is the most complex of the three regarding the coordination efforts involved. Just like in the previous mode, there is a coordinator on site, but the scope of coordination extends to and across the supply chains and between different sites. This mode also typically includes using a consolidation center where materials are co-loaded, to reduce the number of transports to the site.

It is neither possible nor desirable to determine which one of these configurations is the best fit for all contractors. For example, in projects with a low level of prefabricated components, the number of suppliers is higher which makes the coordination effort unfeasible if assigned to a centralized logistics unit (Haglund, Rudberg, & Sezer, 2022). Likewise, strategic logistics decisions should not be handled by local project units in order to gain long-term advantages. Haglund et al.(2022) reinforce the notion that a "one-size-fits-all approach" is disadvantageous for contractors when configuring their logistics. Based on a case study of four cases with different logistics setups they concluded that the level of centralization of the logistics decision-making is affected by the choice of production process. Their findings further imply that formalization can be advantageous for contractors whose logistics operations are complex and varying in nature. These contractors are typically un-specialized do-it-all firms, however, and as such less formalized than their industrial counterparts that specialize in one domain of construction. The authors emphasize that managers need to configure the logistics with the level of prefabrication as well as the completion rate of pre-production designs in mind, as well as consider the potential gain from centralizing the strategic aspects and formalization of the logistics. While do-it-all contractors need to keep operational management of logistics at the individual project level, they could still gain from using standardized and formalized guidelines, as well as specialist knowledge in the early pre-production stages.

Managing, planning, and configuring efficient logistics and supply chain management on construction sites is clearly a complex undertaking, and the logistics need to be tailored to some extent for each project depending on the type of construction and a multitude of other factors. Therefore, the industry must explore the possibility of developing more efficient working methods for logistics through digitalization.

2.6 Digitalization

Digitalization is a wide term, often talked about as a global megatrend. Parida (2018) uses Gartner´s business-centered definition of the term as *"the use of digital technologies to change a business model and provide new revenue and value-producing opportunities; it is the process of moving to a digital business"*. It involves placing advanced technology centrally in the production and delivery of processes, products, and services. Gray & Rumpe (2015) use the same definition but add that digitalization concerns the integration of several technologies into all levels of society that can be digitized. From personal communication through social media to healthcare systems, to activities in politics and government. The authors describe how the concept can take different shapes depending on the settings. For businesses, it can provide information on the optimization of sales, marketing, and customer relations. In manufacturing, digitalization can instead focus on enhancing virtual design processes, and feedback loops between end users and producers through systems embedded in the product itself. In transportation settings, it can provide information on the location, status, contents, or people of links in a supply chain, providing analytical grounds for further development and control of the process.

Given that digitalization is being introduced to virtually every aspect of modern society, the construction sector is no exception (Parida, 2018; Sezer, Thunberg, & Wernicke, 2021). Many new technologies have been, and are currently being, implemented in the construction industry. These include tools such as building information modeling (BIM), Computer-Aided Design (CAD), cloud storage, robotics, and multidimensional design (Sezer et al., 2021). Nowadays, BIM has even become the standard way of working for many companies within the sector, and with innovative technology such as VR, blockchain, and AI, the industry is likely to see profound changes in the way we design and produce buildings and infrastructure (Yevu et al., 2021). In the CLM field, digital tools are yet to become a widespread occurrence (Dubois et al., 2019).

As promising as it may seem, study after study shows that the construction industry is far behind in digital development when compared with other industries and is considered to be one of the least advanced industries regarding inter alia digital assets and digital usage (Agarwal, Chandrasekaran, & Sridhar, 2016). This shortcoming can be explained by a number of factors, but according to Janné & Rudberg (2017), the decentralized, fragmented nature of the construction industry plays a significant role. As each new construction project can be viewed as a temporary organization, where new tendering and procurement of contractors, subcontractors, and suppliers are done each time a project is launched, the central organizing of digital systems becomes complicated. Furthermore, the project-based nature of the industry has contributed to creating a situation where projects become disconnected from the company, and important decisions are in reality moved locally to the management of each project. Sezer et al. (2021) claim that comparing different projects in a contractor firm regarding their degree of digitalization would facilitate the identification of potential benefits that digital tools can bring. The author points out that these types of project-level assessments are lacking in the literature, even though the industry in fact is project-based.

2.6.1 Digitalization of construction logistics

There are a few emerging digital technologies aimed at promoting more efficient logistics in construction production. Whitlock et al. (2018) argue that an important technique is the use of a Delivery Management System (DMS), which is a software system that is centered around a scheduling function. An effective DMS allows the logistics manager(s) to monitor arrivals to the site efficiently by visual scheduling of planned deliveries and resources needed for unloading. While a wide array of different programs exists on the market, they generally deal with information such as weight, volume, and package type of the delivered items, vehicle type and size, and information and contact details of the supplier and recipient of the delivery. This information can be used by the system to create emissions calculations, statistics on delivery trends, and notifications to those affected by the delivery. The standard setup of such a program is based on requests or bookings of a specific time slot placed by a supplier or installer that gets approved or denied by the supervisor of the DMS. These systems thus provide the opportunity for the supervisor (typically the logistics manager) to avoid congestion and material stock buildup, double handling and movement of materials, and to assign the appropriate resources for unloading.

Another technique described by (Whitlock et al., 2018) is the use of tracking technology to monitor the movement of goods from manufacturing to the point of installation. Using tags, either as barcodes or using RFID (Radio Frequency IDentification) technology, information on material movement can be collected and used to identify redundancy in the flows. However, as highlighted by the authors, such systems have proven difficult to implement in the fragmented construction supply chains. Barcodes are unable to hold enough information without manual entries to be efficiently used in CLM, and RFID systems come with a heavy price tag and are rarely compatible with the packaging of construction materials. These types of tracking technology are simply not an appropriate method for construction processes today, as it requires a large effort to implement them early enough to provide value for individual projects.

Some authors argue for more drastic measures. Magill et al. (2022) emphasize that the future of digital logistics tools in construction is the integration with existing BIM technology. Whitlock et al. (2018) highlight how, as a starting point, including logistics functions in 3D BIM models can visualize temporary elevators and tower cranes, as well as access points, storage areas, and staff facilities clearly. This allows better utilization of areas in projects with limited space within and/or around the building´s footprint. The more advanced, recent development of building information technology is called 4D BIM (Magill et al., 2022) and further adds to the potential of integrating CLM. It is developed around including the time component in the three-dimensional information modeling, opening new possibilities for production-, resource, and delivery planning in an integrated setting. This way of conducting the planning work is called Integrated Construction Supply Chain Logistics (ICSCL) and can provide an opportunity for connecting otherwise separate information flows in a project. By visually connecting information regarding production schedule and material deliveries with the geometry of a 3D model, material and equipment flows on site can be optimized. Magill et al. (2022) argue that ICSCL can minimize the risk of production delays due to logistical clashes, and allows project management to utilize all resources available to them should the production fall behind schedule.

Whitlock et al. (2018) argue that 4D BIM can improve the understanding of logistics information, by reducing the difficulty of interpreting logistics solutions and how they change with time in the dynamic environment on site. The article further claims that it can increase the ability to identify safety risks, as well as clash detection through available software. However, the implementation of 4D BIM comes with significant barriers as well. The fact that BIM is mainly used as a design and cost control tool has led to minimal training for on-site project management, according to the authors. The BIM technology is therefore not an available resource for most on-site staff and has instead become the tool of a few select specialists, such as BIM coordinators, architects, and designers. Neither 3D BIM, nor the 4D variety produced at the pre-construction stage is therefore commonly used as a coordination tool for logistics at the production stage. Extensive training for all site staff would be required to make BIM for logistics management a viable option. As it turns out, lack of competence is not the only challenge in implementing digital tools for logistics.

2.6.2 Challenges of implementing digital tools

In order for digital tools to gain traction within CLM, there must be a certain level of digitalization in the project setup, to begin with. For instance, applying logistics in a BIM model will be an impossible undertaking in a project that does not utilize BIM for the design of the building itself. The digitalization of logistics is therefore dependent on the general level of digitalization in a construction project.

Yevu et al. (2021) state that BIM and other smart systems in construction have created much larger information streams than what previously could be expected for a construction project. This surging amount of data creates a need for corresponding digital systems for supply chain and procurement activities to handle the sheer amount of data. However, the implementation of a digital system is a continuous process that requires manual iterations and feedback on the system´s performance if the benefits are to be fully achieved (Civic, 2018). To be able to follow up and measure the performance of a digital system, data must be logged and saved. Before implementation, it must be decided what type of data is to be saved and develop a clear reasoning behind it. Civic (2018) recommends that such decisions should be based on one or several key performance indicators that will be used later in the evaluation stage. Their study showed, however, that there is no tradition of saving data in the construction sector. Due to the fragmented nature of the industry, any data saved from existing IT systems is typically lacking in appropriateness and reliability. This makes the implementation of new systems more difficult, as they risk being perceived as useless when their impact on performance cannot be accurately proven. A reason why the construction industry's current level of digitalization is of importance is the potential for companies to become more cost-effective. Cost overruns constitute a key risk for construction projects. Although the project's total budget may be significant, the contractor´s remaining profit will depend directly on several internal and external factors. Some of these factors are out of the contractor's control, such as those factors labeled as force majeure or unexpected changes in the supplier market. For instance, between 2021 and 2022 construction material prices skyrocketed by 24.4%, an increase not seen since 1981 (Ekberg, 2022). These numbers stress the importance of controlling manageable logistics costs in the production phase, as projects often operate on slim economic margins.

Much has been said in the academic literature about the construction sector´s slow adaptation to the new digital environment in society. Agarwal et al. (2016) emphasize that the research & development spending in construction at 1% of revenue is far lower than that of the auto and aerospace industries at 3,5% and 4,5% respectively. The significant initial investments in new innovative technology are deterring construction companies even when the long-term benefits are communicated clearly. The article attributes this hesitance to the difficulty of implementing digital tools across geographically scattered sites and the varying level of sophistication of the smaller firms. Historically, changes in the sector have been incremental rather than radical. Agarwal et al. argue that this is due to the long-lived idea that every project is unique, and that implementation of new ideas and technology at scale is impractical. Dubois et al. (2019) argue that technological advancement that aims to provide solutions to issues created by the fragmented organization of the industry as it looks today is ineffective. Rather, technologies should provide new ways to increase coordination and reduce the complexity of supply chains, addressing the root of the problem. As projects become increasingly complex, including new materials and environmental demands, digitalization will only become more difficult in the absence of transformational change for the sector. In other words: incremental change is not enough.

2.7 Analytical Framework

The analytical framework is developed to structure the analysis of the empirical results in relation to the theory. The analytical framework (see Figure 2.4 below) covers the relatedness among the research questions and was formed over the course of the research process. The framework connects the research questions and key sections of the theory, as to fulfill the aim of the thesis. Altogether, by applying the analytical framework, conclusions can be identified as a result of the research process. thus, the analytical framework provides a structure for the researcher to follow in the process of analyzing results. Furthermore, it promotes guidance for the reader to understand how the conclusions have been reached.

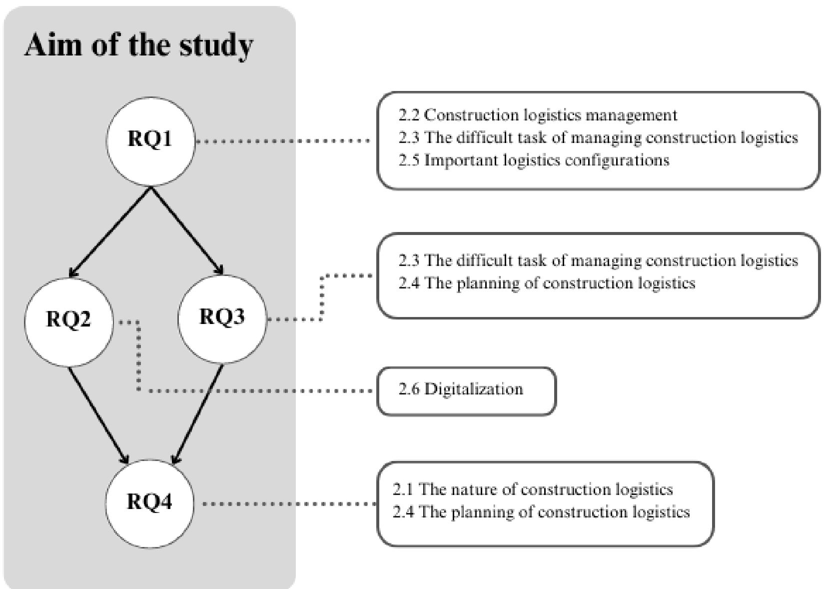

Figure 2.4: The analytical framework of this study.

The analytical framework illustrates how RQ2 and RQ3 can be covered independently of one another, but both of them are dependent on the results in relation to RQ1. RQ4 follows from the results of RQ1, RQ2 and RQ3.

3

Methodology

The following chapter presents the research methodology. First, we briefly describe the case that was the subject of our study. Then the research process is mapped out, explaining the steps of the research including a literature study, interviews, empirical observations and analysis. Furthermore, the research strategy, design and approach will follow, providing context on the choices that were made. Lastly, the quality of the research as well as ethical considerations and implications for sustainability are discussed.

3.1 The case study

In order to illustrate the phenomenon explored in the thesis, we have conducted a case study including three ongoing projects from the Swedish contractor BRA, a construction company primarily operating in the greater metropolitan area of Gothenburg. They employ technical, groundworks, project development, and after-market divisions, but the focus of this study was on their main division, contracting. While they take on a few projects outside of the Gothenburg region, this is where the majority of their operations are. Founded in 2007, they have grown almost exponentially for 15 years. Now, they have a turnover of around 4 BSEK and employ a little over 400 people. Their portfolio ranges from megaprojects to small renovations, and correspondingly, their logistics setups vary a lot with each project organization as there is no central management of logistics. This made BRA a suitable subject for our study, as we were able to study different logistics configurations within the same overall context. Furthermore, the fact that the company is relatively young and still growing means that there are many new employees with individual experiences, not necessarily shaped by a collective narrative from a strong company culture.

3.1.1 Case projects

The case study included three case projects (A, B, and C) situated in or near the city of Gothenburg in Sweden. The choice of case projects was motivated by an ambition to illustrate how different preconditions can influence logistics, and how logistics, in turn, can influence project performance when aided to various degrees by digital tools. All of the projects were ongoing at the time of the study and were producing different types of buildings. The case projects all had pronounced logistics organizations, although these were structured in different ways using varying methods. The projects were chosen with a few different factors in mind (see Table 3.1), such as logistics configuration, size, project price, and surrounding environment. They were chosen to achieve a variation in these factors. Additionally, an important criteria for choosing case projects was availability of information. This was done with the aim of capturing a broad picture of CLM and gaining a nuanced understanding of which project variables create which requirements of logistics management and digital tools.

Table 3.1: The different variables of the case projects

Project	GTA (m2)	Project sum (MSEK)	Type of configuration	Main logistic challenges
A	66 000	circa 1500	Onsite coordinated configuration	Stocking area Access to the building site
B	9500	240	Supply network coordinated configuration	Located within a larger development area
C	43 000	300	De-centralized coordinated configuration	Stocking area around the building footprint Access to the building site Only one crane available

3.2 Research process

The iterative research process that this study entails constitutes four main elements which will be described in this section: a literature study, interviews, empirical observations, and a systematic analysis of results.

3.2.1 Literature study

The research departed from a literature study, providing context on the problem formulation and positioning our research against others in the field. First, an initial review of the literature was conducted to create a knowledge base prior to formulating interview questions, which helped focus the topics of the interviews. Throughout the interview and analysis process, the literature study was revisited and expanded to contextualize the empirical findings. Literature was primarily obtained through scientific databases such as Chalmers Library, Scopus, and Google Scholar, although articles from industry and scientific magazines or thesis work were considered to some extent to complement the theoretical framework. Keywords such as: "logistics", "construction logistics", "logistics management", "supply chain management", "third-party logistics", "digitalization", "digital tools" and "just in time" were included in various combinations in the search for relevant articles. Articles were chosen based on publishing date, geographic relevance, and credibility (in terms of the number of citations and coherence with the field). Information about specific digital tools was gathered from their respective websites. The purpose of the literature study was to gain a better understanding and provide a framework for analyzing the empirical results.

3.2.2 Interviews

Following the initial literature study, 16 semi-structured interviews were held with relevant actors in and out of the different projects. Interviews are a common means of data collection, particularly in qualitative research (Bryman, Bell, & Harley, 2019). The semi-structured interview format relies on a general schedule and set of questions but allows the interviewer to vary the sequence and add follow-up questions. The questions can be a mix of closed and open-ended, often departing from closed questions to gather basic information, and then moving into more open territory, Bell argues. This format allowed the respondents of our study to branch out and develop longer lines of reasoning for subjects they feel strongly about, and as such was an appropriate choice for exploring complex relationships within construction logistics. Additionally, we were able to slightly modify the set of questions based on the role of each respondent. The aim of these interviews was to gather first-hand data on the experiences and opinions of people involved in and affected by the logistics activities in the different projects.

However, it is important to be aware of the fact that the interview situation is something out of the ordinary for the interviewee. As Bell et al. (2019) point out, the interviewee may associate the event with previous negative or positive experiences, and we cannot know what state of emotion they are in at the start of each session. While a semi-structured interview is more resembling a conversation than the more formal varieties, one cannot assume that the interviewee will be comfortable entering the situation. Therefore, interviews were held at a time of the respondents choosing, in person at their place of work when possible, and otherwise via video call through Microsoft Teams. To further promote the comfort of the interviewees, all interviews were held in Swedish, and subsequently, any quotes included in the results have been translated into English. All respondents of our study were asked for consent to be recorded by audio.

3.2.2.1 Roles of respondents

To gain a deeper understanding of the logistics of the three projects, people in different positions were interviewed. This provided a more accurate representation of the collective experience and helped highlight contrasting opinions. All respondents are listed in Table 3.2 below in the order in which they were interviewed.

Table 3.2: Lists of respondents and their respective roles, company, project affiliation, and mode of interview

Interview no.	Role	Company	Project affiliation	Interview mode
1	Logistics manager	BRA	A	Onsite
2	Logistics leader	BRA	A	Onsite
3	Department manager	BRA	A	Onsite
4	TPL Project manager	Bimensions	A & B	Onsite
5	Calculation engineer	Tornstaden	Other	Onsite
6	Logistics manager	PEAB	Other	Digital
7	Site manager	BRA	A	Onsite
8	Machine operator (subcontractor)	Kranpunkten	A	Onsite
9	Site manager	BRA	B	Onsite
10	TPL Logistics specialist	Svensk Bygglogistik	Other	Digital
11	Calculation engineer	Tornstaden	Other	Digital
12	Logistics manager	AF	Other	Digital
13	Supervisor	BRA	B	Onsite
14	Block manager	BRA	A	Onsite
15	Supervisor	BRA	C	Onsite
16	Site manager	BRA	C	Onsite

Department manager: One department manager from BRA was included in the study. Department managers have the highest authority in the projects and work strategically, maintaining relationships with the clients and bringing new projects to the drawing table. Typically, they are responsible for several ongoing projects in a geographic or business-related area.

Site managers: We interviewed the three site managers of the case projects since they have the most comprehensive knowledge of activities on their site and have the most prominent operational influence. All of them had over 20 years of experience and different philosophies regarding logistics and digitalization.

Logistics managers: The study included three logistics managers active in production. One was the head of a logistics group at one of the case projects. The others were from PEAB and AF and were interviewed to broaden the understanding of the contractor´s logistics. All of them answer directly to their respective site manager and are in charge of all logistics operations onsite.

Logistics leader: One logistics leader from BRA was included in their role in the logistics organization. They are subordinate to the logistics manager and manage selected areas of logistics. The logistics leader included in this study is responsible for a day-time material handling crew and inspection of the work environment on site, among other tasks.

Block manager: The block manager that was included in our study is responsible for four supervisors and is in charge of a few aspects of production at Project A, as a partial site manager of sorts. They had previously been involved in the design phase and needs to cooperate with the logistics group to bring in materials to the site.

Supervisors: We interviewed two supervisors who have logistical responsibilities as part of their job description, but their primary work is managing core production-related activities. Supervisors are often the “eyes on the ground”, having the closest relationship to subcontractors and workers on site.

Calculation engineers: Two calculation engineers were interviewed to increase our understanding of how logistics is considered in the tendering and budgeting phase of projects. They were both unrelated to the case projects from BRA and worked for the company Tornstaden.

TPL actors: Two respondents came from third-party logistics providers. One of them was a logistics specialist from the company Svensk Bygglogistik, who had helped develop a digital DMS and currently conducts business research. He was included for his knowledge of logistics trends across the industry. The other was a project manager who is the owner of a TPL company, Bimensions, that offers services such as logistics planning, Construction Consolidation Centers (CCCs), and material handling. This company is an actor in all three case projects.

Machine operator: A telehandler operator was interviewed due to their first-hand experience of handling deliveries onsite. They have been working on a multitude of projects all over Sweden for more than 10 years. He is hired as a subcontractor at Project A through the company Kranpunkten and is permanently posted there to unload materials and manage the 70+ lifts on site.

Table 3.3: Number of respondents per company.

Company	No. of respondents
BRA	9
Bimensions	1*
Svensk Bygglogistik	1
PEAB	1
Tornstaden	2
AF	1
Kranpunkten	1*

* = subcontractor in the case projects

Since this study focused on the construction logistics of the company BRA, the majority of the respondents were BRA employees involved in the three case projects. Beyond the respondents from BRA´s projects, as shown in Table 3.3 above, seven people from other companies within the construction industry were interviewed. Two of them (*) were hired as subcontractors in BRA´s projects. These “external” respondents were chosen to contribute with a wider variety of perspectives, coming from other organizational contexts with other relationships to construction logistics. These interviews brought insights beyond the boundaries of BRA´s culture and working methods, adding to the trustworthiness and applicability of the study. These respondents were mainly actors who have experience in construction logistics or are involved in the tendering phase. In summary, the empirical study consists of 16 actors who in some way include construction logistics in their everyday work.

Table 3.4: Number of respondents per project affiliation

Project affiliation	No. of respondents
A	7
B	3
C	2
Other	5

The sample size of interviewees was selected proportionally to the number of logistics staff in the site management of each project. As Project A had the largest project organization by a significant margin, a larger sample size was chosen to provide a representative understanding of the organization and the project as a whole. Correspondingly, the site management of Project C was a fraction of the size and as such required fewer interviewees to gain the same level of understanding in relation to the available information. One of the respondents with an external position is affiliated with more than one of the projects, and as such is included in more than one row in Table 3.4 above.

3.2.3 Empirical observations

The empirical results from the interviews were supported further by carrying out observations on sites in the daily logistics operations, through passive observation in meetings, on safety inspection rounds, and several site visits and tours with logistics personnel. We spent considerable time compiling our results at a field office of Project A, which allowed us to pick up information from informal and casual meetings between employees. This increased our understanding of the organizational culture and informal hierarchies, which added nuance to the results of our study.

3.2.4 Analysis of results

The audio recordings of each interview were transcribed word for word in separate documents, along with notes taken during the interview. The resulting texts were then read through several times until an understanding of the collected data was reached and a number of themes emerged. The identified themes were:

- Procurement, contracts, and design
- Organization and leadership
- Digital tools
- Logistics-related problems
- Deliveries and material handling
- Third-party logistics
- Social and environmental sustainability

The transcripts were then color-coded by theme, and each theme was compiled and reworked into sections of the result chapter. Findings from the interview study were then either supported or contradicted by the empirical observations. The results were then discussed in relation to the theoretical framework to reach conclusions.

3.3 Research strategy, design & approach

Upon diving into the complex field of construction logistics, we soon settled on a qualitative research strategy. While quantitative research would have allowed us to further isolate and quantify specific phenomena within the topic, it would likely fall short in capturing the complex social patterns that are an inherent part of the fragmented construction process. Quantitative research strategy relies largely on positivism, meaning it emphasizes the existence of objective social reality and therefore first-hand observation or measuring as the correct method of research (Bryman et al., 2019). Qualitative research instead values naturalism, meaning it attempts to gather detailed descriptions of people´s experiences and create an understanding of the social reality through them without imposing predetermined ideas on them. By understanding how the individuals taking part in the context interpret it, researchers can generate theory inductively. As we wanted to explore the experiences of people who deal with construction logistics in their daily work and provide recommendations that would benefit them, we found that their context is best understood through qualitative research.

Case studies can illustrate a problem in ways that other research designs cannot (Bryman et al., 2019). By creating a detailed narrative of real-life situations and events, the case study can be used to generate theoretical arguments that are generalizable beyond the specific case. Commonly combined with qualitative methods such as unstructured interviews and observations, the case study aims to understand real interactions and highlight the context in which the events occur. We chose a case study design to be able to generate new theories that are relevant both for the industry and for future research.

This study is based on abductive reasoning. Bryman et al. (2019) argue that abductive logic relieves the researcher of the strict process of deductive reasoning where theories and hypotheses have to be tested and disproven. Instead, an abduction builds on an iterative process where the researcher moves back and forth between empirical results and literature in an effort to explain complex phenomena in the real world. We have applied an abductive logic described by Dubois & Gadde (2002) as *systematic combining*. This logic entails non-linear case studies where the understanding of theory and empirical observation is interdependent and constantly evolves. New empirical findings create a need for the expansion of the theory and vice versa. This process allowed us to find results we were unprepared for, instead of gathering data with the sole intent of confirming or disproving a predefined hypothesis. Such an approach was well suited to the semi-structured interview format, as unexpected results surfaced when interviewees were allowed to branch out. For example, our research questions have been altered due to new findings from the interviews, meaning the theory had to be developed further as well.

3.4 Research quality

This study and its findings are representative of the context observed at BRA but may be applicable to other companies in the industry as well. Bryman et al. (2019) claim that much academic disagreement has revolved around the external validity or generalizability of case studies. Critics question whether findings from a single case can be seen as representative in a way that they are applicable in a general fashion to other cases. However, Flyvbjerg (2006) is confident that this is a misconception and adds that generalizability is overvalued as scientific progress, a remnant of natural science norms that have influenced the realm of social science. On the contrary, Flyvbjerg argues that case studies present an opportunity to gather "in-depth, context-dependent knowledge", avoiding the "academic blind alleys" of uselessness in the real world that distance to the subjects of a study can result in. Furthermore, he points out that case studies develop the researchers' own context-dependent knowledge and thereby provide a basis for better research.

The nature of the three different projects and their organizations would have made it counterproductive to attempt to maintain an equal level of scrutiny. Project A was the largest by any measure, and as such required the most research attention. Project B was the smallest by size and budget but was part of a larger logistics network within the area, and as such the complexity of case project B required a medium level of attention. Project C was the least complex to understand as researchers and was prioritized accordingly. This proportional research effort can be justified given that the study has reached a similar level of understanding of each of the cases as a share of all available information. However, it may or may not have inclined us as researchers to be influenced more by the subjects with whom we spent more time. We wish to emphasize that throughout the process our ambition has always been to remain objective and value the interpretations of each respondent equally.

3.5 Ethical aspects and implications for sustainability

This study has been conducted with the academic honesty and integrity of participants as guiding principles. Bryman et al. (2019) emphasize four main ethical principles to consider in business research:

1. Avoidance of harm
2. Informed consent
3. Privacy

4. Preventing deception

The first principle, *avoidance of harm* concerns the physical and mental well-being of the study´s participants, and to some extent, researchers. This includes stress, harm to a participant´s career, self-esteem, or person. It is particularly prevalent in qualitative research, where anonymity is a complex task. While our study mainly focuses on matters of production in construction, rather than personal matters, there has been a careful selection of quotes and examples to avoid any type of harm to the participants or the companies that are involved.

The second principle, *informed consent*, regards the information participants are given prior to participating. They should be given enough information about the study to be able to decide whether to participate or not freely. In our study, participants were given an introduction by email before each interview. At the start of each interview, they were briefed about the purpose of the study and their participation, and before the interview commenced, they were asked for consent to an audio recording. Additionally, our ongoing research was featured in a weekly newsletter at BRA, informing employees about our aim and who we are.

Privacy, the third principle, is strongly connected to the principle of informed consent. By giving their consent, participants are in a way giving up parts of their privacy within the agreed-upon context of the study, Bryman et al. argue. That being said, they may still refrain from answering questions they feel uncomfortable with. Any information obtained through the interviews in our study that can reveal the identity of a respondent has been treated carefully, and only been included in the report with the respondent´s knowledge and approval. Any personal information not included in the report was stored only when necessary and has been deleted once the report is approved in accordance with GDPR.

Lastly, Bryman et al. (2019) highlight the ethical principle of *preventing deception.* In research, it is important to avoid deception, in the sense of presenting research as something it is not. For example, if a researcher was to pose as a professional to gain company information, that would be unethical and seen as deception. We have pursued integrity and honesty throughout the process and have not encountered any signs of deception when reviewing our work.

A contemporary issue for the academic world is the emergence of advanced Artificial Intelligence (AI) software. The development of such systems is inherently exponential, since AI learns constantly as it is fed with new information. An AI bot could undoubtedly, if not today then within the foreseeable future produce credible research reports, articles, and books with just a few inputs from the researcher. This is uncharted territory for the field of scholars and researchers that have learned the traditional and accepted methods but may very well alter the character of scientific research drastically. While we believe such technology holds great potential for society at large, we assert that in no way has AI been used to produce or aid the writing of this report.

The implications of our study and its findings contribute to the development of utilizing logistic methods and digital tools which could help decrease construction companies' environmental impact. The reason for this is that streamlined and optimized production processes are proven to decrease the waste of resources and reduce the number of transports to and from the building site. During the study, it was found that literature often makes a connection between construction and CO2 emissions from transport in logistics-related aspects. With this in mind, we chose to focus on the environmental impact of efficient delivery planning in regard to transportation emissions, even though material waste plays an important role in a project's environmental sustainability as well. The decreased climate impact would have a positive effect on the industry's contribution to greenhouse gas effect and thereby society as a whole. Another sustainability factor considered in this report is social sustainability. This has been taken into consideration as the empirical study showed a clear connection between construction logistics, safety on the building site, and stress-related health of the workforce. An increased digitalization and advancement in logistics organization may lead to altered job descriptions and new roles within the company in the future, which then could have an impact on the individual´s lives.

4

Results

This chapter presents the results of the empirical study. First, it describes the digital tools for construction logistics that were identified, followed by the scrutinizing of construction logistics in each of the case projects. Thereafter, findings regarding the usability of digital tools and logistics setups are compiled. Lastly, organizational and project preconditions for well-functioning logistics are brought forward.

4.1 Digital tools in construction logistics

During the empirical study, six different digital tools related to construction logistics that are used to varying degrees within the case projects were identified. Four of the digital systems are used in the projects exclusively intended for logistics management (LogNet, Myloc, Trello, QLocx), and two of them are tools that have select functions applicable to logistics (Dalux, Infobric).

4.1.1 Lognet

LogNet is a web-based Delivery Management System (DMS) that is centered around a digital delivery schedule. It is owned and developed by the Swedish Third party Logistics (TPL) provider Svensk Bygglogistik. The system relies on bookings made by, for example, subcontractors and supervisors who intend to bring material to the site. Through Lognet, different actors involved in the project have the possibility to book time slots for each delivery and specify information such as the type of package, weight, volume, resources needed for unloading, and desired destination within the site. If the building site has several unloading zones, the booker is able to select which zone should be used as well. The idea is to have an interface that shows deliveries in a clear way that all relevant actors are able to access (see Figure 4.1).

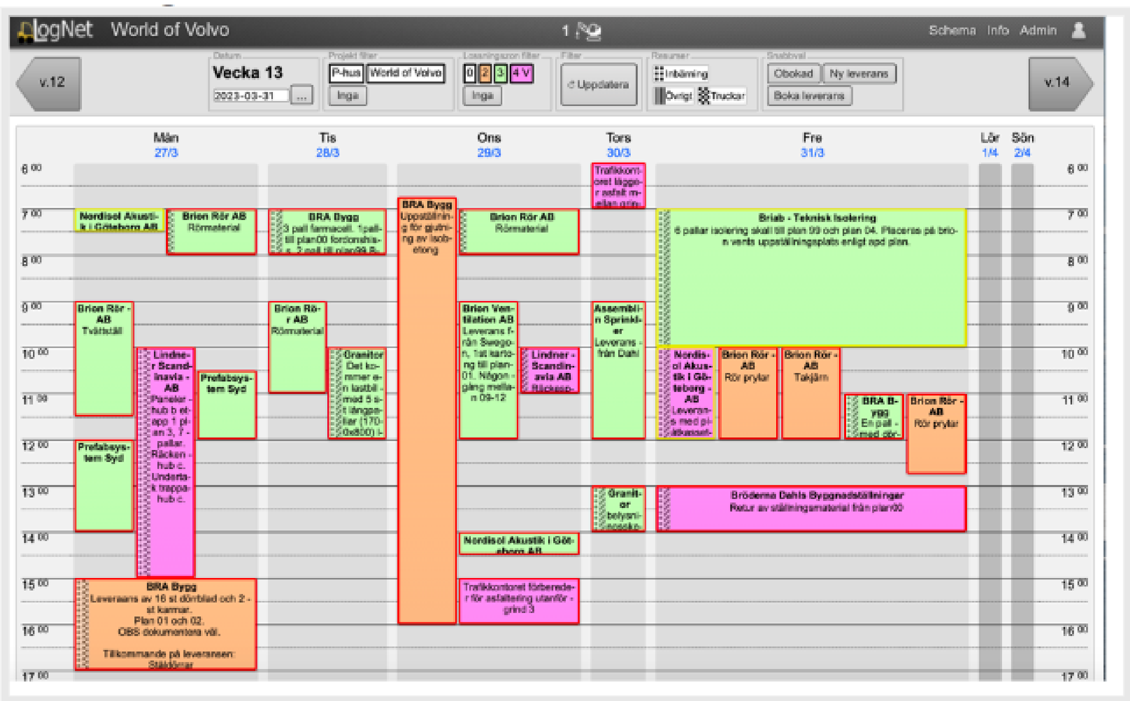

Figure 4.1: An example of the layout of the DMS Lognet (taken from Project A.

Lognet is intended to be monitored by the person or team, usually from the supplier of the system or from the main contractor who is responsible for the on-site logistics. Arrival and departure times can be noted for each delivery, and unscheduled deliveries that arrive unexpectedly can be documented. The system is also able to automatically provide statistics on the timeliness of bookings and deliveries, as well as CO_2 calculations based on the number and type of vehicles. However, to gain these benefits the information running through the system has to be followed up manually, meaning that someone must confirm that deliveries were made on time, and within the correct regulations.

BRA bought this service for Project A, although they have only bought the right to use Lognet as a system. The cost of such a license is just over 10 000 SEK/month. The logistics specialist from Svensk Bygglogistik emphasized that their business idea is not selling one-off product licenses to contractors, but to include Lognet free of charge when offering their consultancy services as TPL providers, meaning that they offer a consultant who is placed on the building site solemnly to manage the construction logistics. Therefore, Lognet is only used by around 20 projects at a time, and although the clients usually are big projects, this makes them much smaller than their competitors in terms of the number of users.

4.1.2 Myloc

Myloc Construction is a cloud-based DMS that exists both as a website and in an app format (Myloc Construction Go) and is the biggest competitor to the supplier of Lognet. The system is designed to involve construction developers, contractors, suppliers, and potential logistics partners. The vision of Myloc is to simplify the process for companies to enter and develop logistic networks. Similar to Lognet, Myloc revolves around a delivery schedule but presents itself through a more modern and developed interface (see Figure 4.2). The cost of the Myloc Construction license is higher than the cost of Lognet but is determined on an individual project or exploitation basis. Apart from the DMS, Myloc offers other functionalities such as connectivity to labeling systems. This makes it possible to oversee the number and types of materials that are stored in a terminal or Construction Consolidation Center (CCC) directly on the website or app, simplifying the planning needed for joint deliveries of materials to the building site.

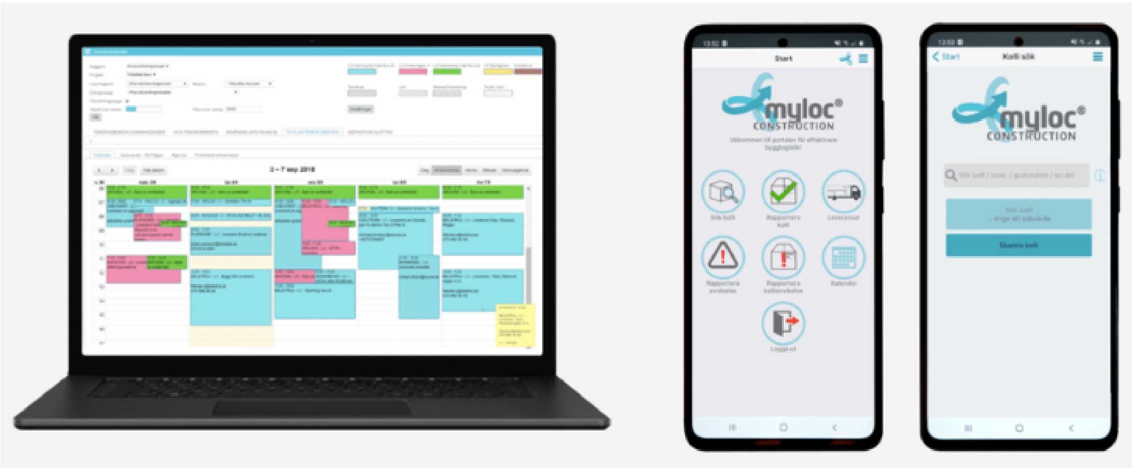

Figure 4.2: An example of the layout of the DMS Myloc (Sandlund, n.d.).

4.1.3 Trello

Trello is a web and app-based tool that works like a digital whiteboard for task distribution. Launched in 2011, Trello now claims to have two million teams utilizing their software. There are premium subscription packages that include timelines and calendar functions, but the free baseline version was the one used in the case projects. By stacking tasks in to-do lists on the digital board, logistics managers can use Trello to delegate tasks throughout their team such as material handling, cleaning, or construction of temporary elements such as doors, ramps, and passageways. Any task that a manager wishes to delegate can be described both in text and photographs, and the assigned workers can mark the task as completed when finished.

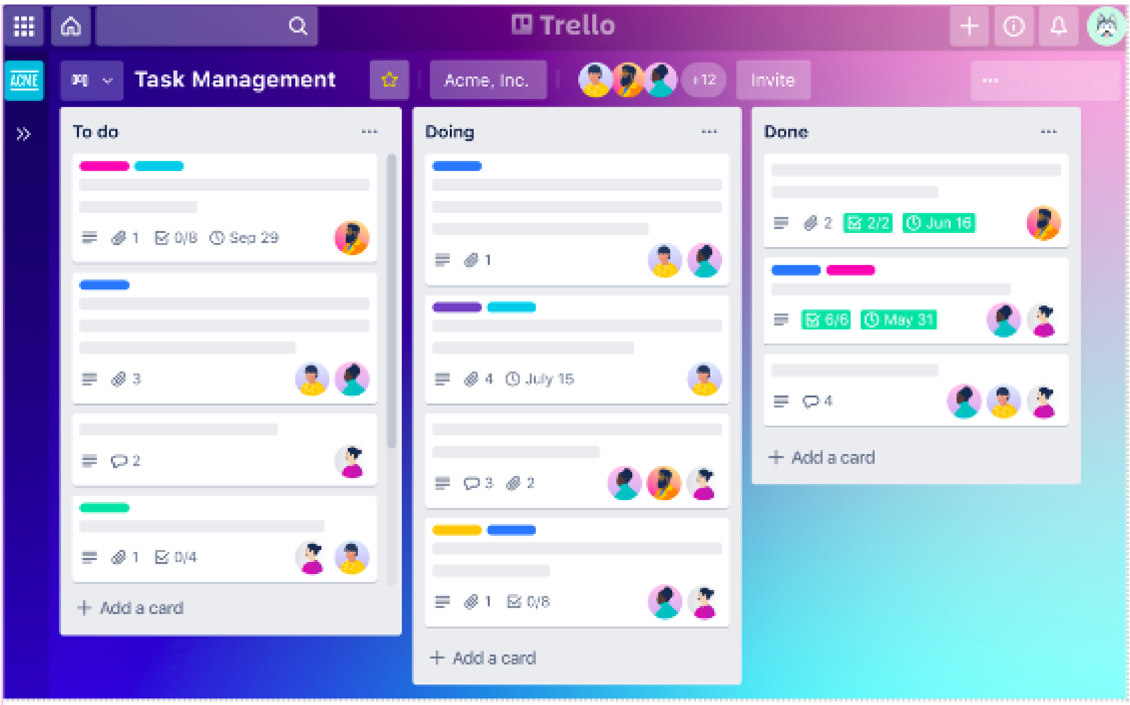

Figure 4.3: An example of the layout of the task distribution system Trello (Trello, n.d.)

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4.1.4 QLocx Delivery Container

QLocx delivery container is a system that aims to minimize the interaction between the courier and the recipient onsite for small packages. The concept is to place a freight container as part of the site perimeter, with one door on either side of the boundaries of the site. The doors are fitted with digital locks, and the carrier accesses the outside door via a single-use digital key in the QLocx app connected to the individual parcel. The person receiving the goods then gets a notification of delivery via the digital app platform and can pick up the package from the container when it suits them. According to the QLocx website, small goods make up more than half of the deliveries to the construction site, meaning that the system can potentially reduce the traffic on site significantly. The platform provides statistics on the number of deliveries and estimates the total time savings for site management, based on the assumption that an average of 20 minutes per package is otherwise spent receiving phone calls, meeting the carrier, and signing the delivery. Qlocx sells their system to container rental companies who rent out the container to construction firms for around 5000 SEK per month. Assuming that the cost of a supervisor is around 500 SEK/hour, the project needs to receive at least 30 deliveries per month through the container to cover the cost of the system.

Figure 4.4: Qlocx digital lock inside the container(left) & Qlocx delivery container placed in site perimeter(right) (own images).

4.1.5 Dalux

According to their website, Dalux is the largest Building Information Modeling (BIM) company in Europe. Developed in Denmark starting in 2005, they claim to have more than 700 000 users. Their BIM software is used in 147 countries and features functions such as in-model task lists and communication. While it is not exclusively used for logistics purposes, there are some functions to be utilized. The logistical Dalux applications identified at BRA were the creation of work allocation plans (WAPs).

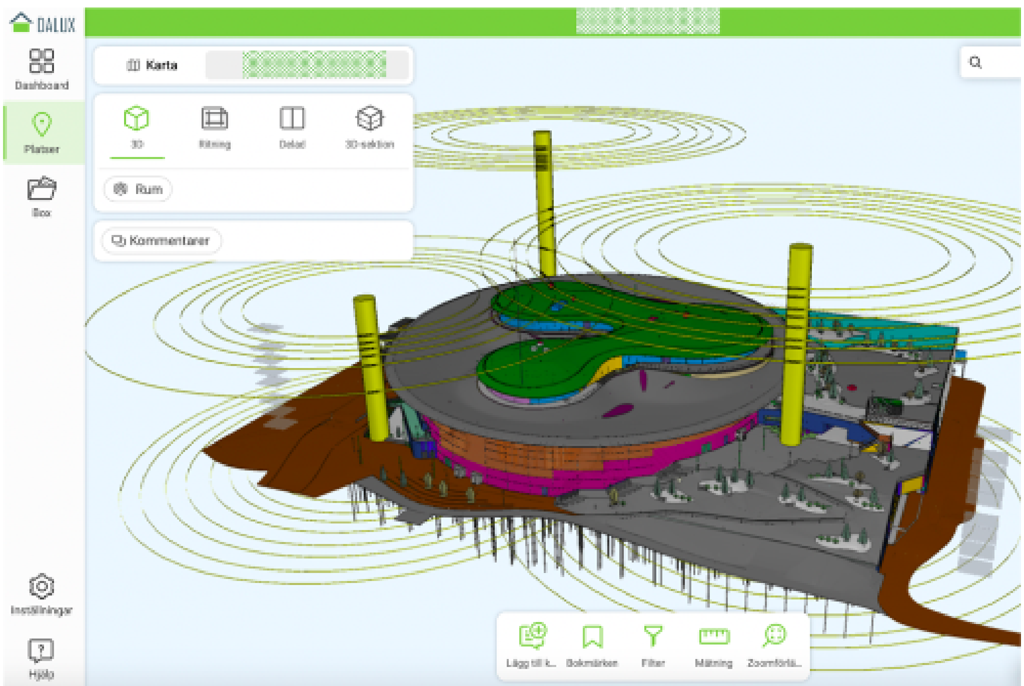

Figure 4.5: An example of the layout of the BIM-viewer offered in Dalux (image provided by BRA).

The BIM-viewer is free to use, but the full packages of Dalux applications are priced based on the number of users and features. The monthly price of a license in one of the case projects ranges from 5200 SEK/month for "Dalux field" (task management), to 7300 SEK/month for "Dalux box" (document and BIM coordination). As Dalux is not primarily a tool for logistics, the cost of the licenses is not representative of the logistics use alone.

4.1.6 Infobric

Infobric is perhaps most known in the industry as a digital system for the legally required monitoring of staff attendance via the identification card system id06, but a logistics application of the system is an app-based software for weekly safety and environmental inspection rounds on site. Users set up a palette of criteria such as the cleanliness of working areas, presence of fall protection, waste management, or the condition of lifting equipment and machines, etc. On-site management brings a tablet or a phone on their rounds and creates digital lists of deviations from the rules/criteria. These deviation points can be assigned to the actor responsible for resolving the point and complemented with photographs, comments, and positions on the WAP.

Infobric is owned by the investment company Summa Equity and is priced based on the project value. The monthly cost depends also on the choice of service packages, and in one of the case projects it is approximately 4500 SEK/month.

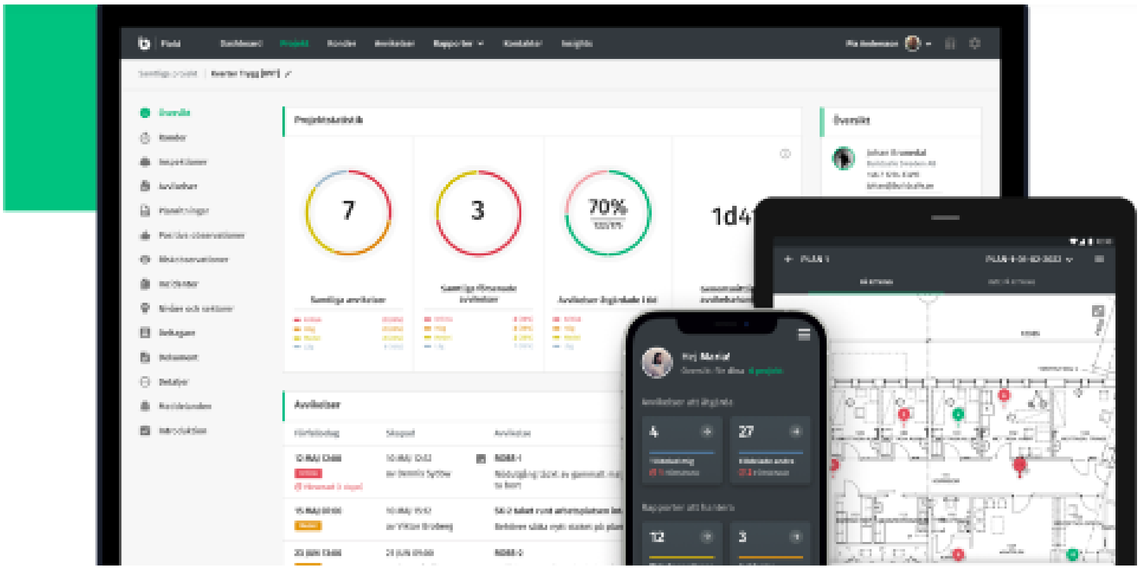

Figure 4.6: An example of the layout in Infrobric, used as a task distribution system for inspection rounds (Infobric, n.d.).

4.2 Case Projects in the empirical inquiry

The empirical study revealed significant differences between Projects A, B, and C in terms of how they organize and perform their logistics activities. This was found to partly be due to the preconditions of each project such as the geographical location of the project, the kind of building that was constructed, as well as elements of the surrounding area. However, it was also found that the logistics setups used had been introduced to the projects in different ways and under diverse circumstances, which has resulted in the setups being maintained with varying effects and success between the projects. In Table 4.1 below, some of the influencing preconditions and chosen logistics strategies are shown, as well as the subsequent logistics setups, digital tools, and organization of logistics management are presented.

Table 4.1: Preconditions and logistic strategies of the construction projects.

Project	Geographic preconditions	CLM organization	Logistics Methods	Digital tools	External logistics actors
A	Located centrally in direct connection to a busy traffic node, with neighboring construction sites	Dedicated CLM-team led by a logistics manager and a logistics leader	JIT	LogNet QLocx Trello Dalux Infobric	Subcontractors dedicated to material handling and cleaning onsite
B	Part of a larger, tightly configured construction development situated in a industrial area.	CLM is part of one supervisor's responsibilities. Overall logistics within the development area is coordinated by a TPL	Checkpoint-solution TPL	Myloc Trello Dalux Infobric	Checkpoint operation and development area logistics coordination is managed by TPL. Material handling and cleaning onsite is handled by subcontractors
C	Situated in the city centre with very little space available on the building site. Lies within meters of residential buildings and heavily affected by adjacent subway construction	CLM is part of one supervisor's responsibilities	JIT	Dalux Infobric	Subcontractors dedicated to material handling and managing lifts with the crane

4.3 Project A

Project A is a large, high-profile project located centrally in Gothenburg near both the highway and busy public transport hubs. It comprises a complex, architecturally recognized "experience center" of 22000 sqm, as well as a parking garage of 45000 sqm. It is the single largest project in BRA´s portfolio at about 1,5 billion SEK and is expected to be completed within a year. On an average day, there are 250-300 workers on site and 20-30 members of site management staff, as well as a client organization of 20 people in an adjacent office. The site management is divided into five blocks: three groups responsible for production, one for procurement and design, and one logistics group. The production is highly influenced by the geographical location of the projects as it is situated close to one of Gothenburg's busiest traffic nodes. In addition to this, there is limited space outside the building footprint which makes the project sensitive to delays in deliveries and carry-in of materials. Another highly influencing factor is the large structural laminated timber components involved, which had to be specially made in other countries and required the closing of several roads within the central city. Figure 4.7 displays the architectural design of the building and a WAP in Dalux, as well as a carry-in of roof materials by helicopter.

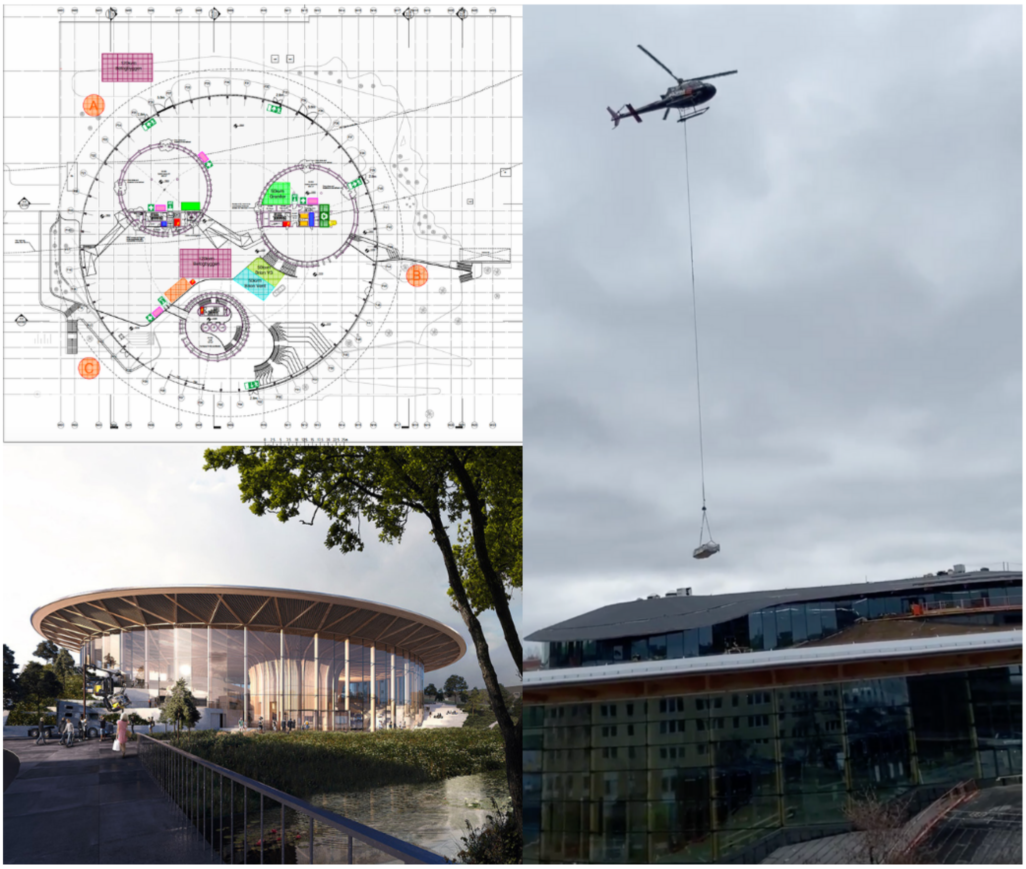

Figure 4.7: Project A: Internal WAP of the third floor (top left), digital rendering of the construction (bottom left) & material handling from the unloading zone to the roof by helicopter (right). Images provided by BRA.

4.3.1 Logistics organization at Project A

The logistics organization of the project was initiated in the design phase by the site manager and is continuously developed as production commences. It consists of 22 people in total: a logistics manager, a logistics leader, an administrator, three carpenters, three truck drivers, two crane drivers, two cleaners from an external firm, and 9 workers from an external logistics firm. The logistics manager is the head of the group and reports to the site manager. Together with the logistics leader they manage the flow of materials from suppliers to the point of installation inside the building. They are also in charge of all temporary lighting and heating, as well as temporary installments such as stairs, ramps, elevators, and cranes. The logistics group at Project A is also in charge of waste management and monitors the overall cleanliness and working environment on site, even though the site manager is ultimately responsible for safety. Their working methods come off as established throughout the ranks, both within BRA and by the subcontractors. The project manager from the external logistics firm believes that Project A currently has saved around 10-12% of total costs by using this logistics group. However, the site manager states that the logistics organization comes with a heavy price tag, as the logistics activities are estimated to accumulate circa 1,3% of the total project costs.

4.3.2 Digital logistics tools at Project A

Project A utilizes five of the six previously mentioned digital tools related to logistics where three of them, Lognet, Trello, and Qlocx are used specifically for logistics management purposes. Table 4.2 presents a summary of digital tools related to logistics used in Project A and how they are utilized. Figure 4.8 below illustrates the flow of information through the five digital tools.

Table 4.2: Digital tools utilized for logistics activities in Project A.

Tool	Application for CLM	Responsible actor	Users of tools
LogNet	Delivery planning and control	Logistics manager	Logistics group Block managers BRA supervisors Foremen of subcontractors
Trello	Task distribution	Logistics manager Logistics leader	Logistics group
Qlocx	Receiving small goods	Logistics manager Logistics leader	Supervisors Suppliers
Infobric	Digital safety and environment inspection round protocols	Logistics leader	Supervisors Representatives of entrepreneurs on site
Dalux	Task distribution through WAPs	Logistics manager	All relevant actors

Through the digital DMS LogNet, subcontractors and supervisors book the unloading of deliveries, material distribution from the unloading zone to the point of installation, as well as cleaning of the working areas. Materials typically arrive in the morning at designated unloading zones and are cleared by the distribution team during the afternoon and evening. This flow is crucial to the project, as the only area available for unloading is one street along one side of the building. The street had to be cleared every day in order for any deliveries to be received and unloaded in the limited space the next morning. Given that the project had seen about 250 deliveries a day at its peak, it is not an easy task to coordinate this flow. However, at the time of the study, the average number of transports is closer to 40 per week. Observations show that while the booking routine is established throughout the project block the logistics manager and their staff do not utilize the full potential of the DMS. Oftentimes, the arrival of deliveries is visually confirmed by the machine operator or a supervisor, but turnaround times are not documented in LogNet. It was found that this has two consequences. Firstly, the statistics obtained from the system are not representative of the timeliness of deliveries, and secondly, BRA risk missing out on reclaiming time-specific delivery fees from suppliers when deliveries arrive late.

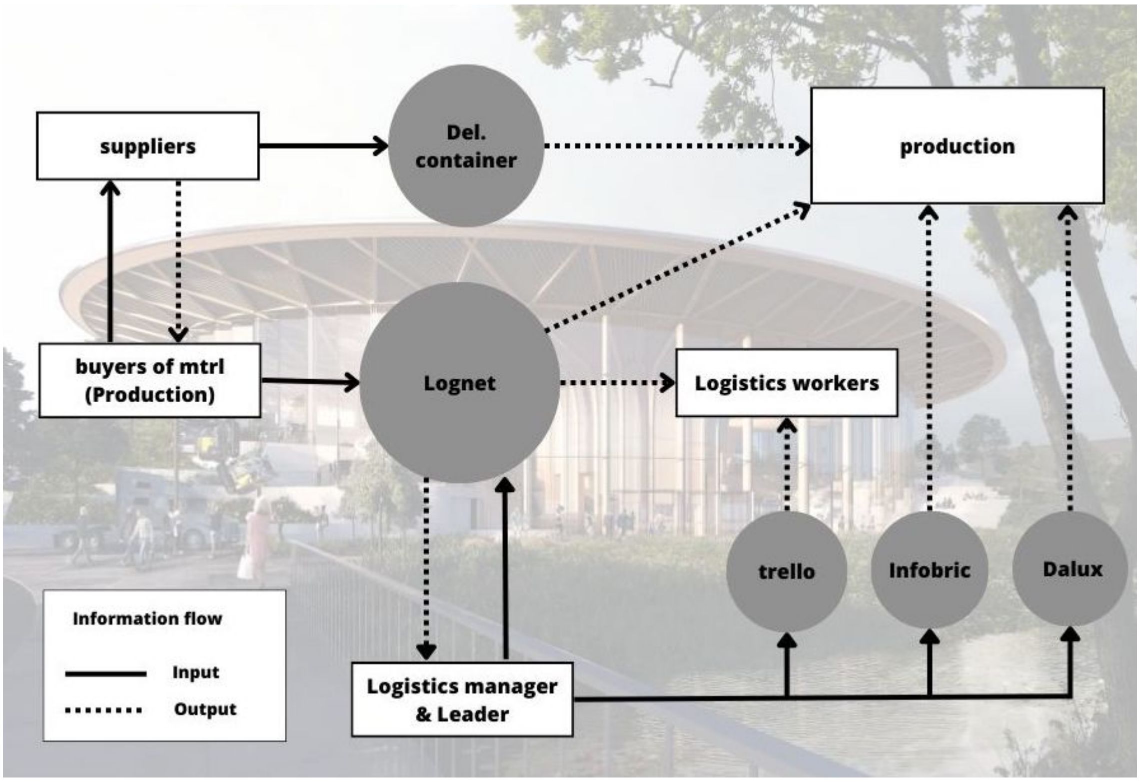

Figure 4.8: The information flow through digital tools for logistics at Project A.

To coordinate the workers of the logistics group and maintain this flow of materials from the street to the desired floor and room, the logistics manager and leader use Trello. Using the app, they delegate tasks such as material distribution, the construction of temporary ramps or walls, floor coverings, or railings for fall protection. The app allows them to follow the progress in real-time and maintain overall control of the work the logistics group is doing without constantly being present. The logistics manager usually tries to plan the workers' schedule one day ahead, which sometimes fails when unforeseen events occur such as water leaks or unbooked deliveries. The number of unbooked deliveries to the project is estimated to be about 20%.

To mitigate the number of small delivery vans entering the site, the logistics group at Project A implemented the use of a Qlocx delivery container, which is the first of its kind used by BRA. This container is placed at the perimeter of the site, with one door on either side. Selected suppliers and foremen on site have access to the container through the app-based system. Thereby, next-day-delivery type suppliers of smaller packages do not enter the site gates, which has shown to be almost half the number of inbound vehicles per week.

Every subcontractor has designated storage areas within the building and in the parking garage for tools and equipment. It is specified in the subcontractor´s contracts that the storage allowance is two weeks' worth of material maximum. Building materials are stored in areas marked on the internal WAPs, created in Dalux. The

WAPs are updated on a weekly basis and contain detailed information for each floor and the outdoor space.

4.3.3 Client's requirements

The client of Project A is a vehicle manufacturer with high ambitions regarding the aesthetic expression of the building and its finishing materials. According to the respondents, rather than placing explicit demands on how to perform the construction logistics, the client has high expectations on the agreed production time plans, which in turn, require adequate support functions. However, the client demands that all vehicles that enter the site perimeter be of their own making. While being a source of reputability and good PR for them as vehicle manufacturers to have built a project using only their own transportation vehicles and excavation machinery, the demand presents some unusual challenges and additional costs for BRA´s coordination of the supply chain. In some cases, deliveries have to be reloaded onto trucks of the client´s label in other countries before arriving at the site. Others have to be refused entry at the gates.

4.4 Project B

The second case project is located in the municipality of Mölndal, outside of Gothenburg, and is part of a cluster comprising in total 8 different projects in the first phase of a larger development. BRA is assigned as the main contractor for three ongoing and two already finished buildings within the development area. The total GTA of these buildings is almost twice that of Project A, but each building is handled as a separate project with individual organizations. This case focuses on one of the projects constructed by BRA (hereafter referred to as Project B), an ongoing 7-floor project of in total 9500 sqm that includes both office space (stop-standard) and 60 apartments for elderly co-living, see Figure 4.9 below. On an average day, there are around 60 workers on site.

Figure 4.9: Project B: Digital rendering of the building (left) and a WAP of the development area where Project B is labeled "Lott A" (right) (images provided by BRA).

4.4.1 Logistics organization at Project B

There is no dedicated logistics-only employee for this individual project, but logistics management is included in the job description of one of the (three) supervisors from BRA, who handles delivery bookings, waste management, and storage of materials. The supervisor started planning the construction logistics together with the site manager around the time of the casting of the slab. Their responsibilities only range to the perimeters of Project B, and not the development area. The site management does not arrange regular meetings solely for logistics but includes them in their weekly meetings with subcontractors.

Although the geographical location itself poses little logistical challenges being near a major highway in an industrial area, the development area is tightly configured with only two main access roads within the overall fenced perimeter. The flow of traffic through the gates is therefore a mix of vehicles bound for different projects belonging to different contractors, each at different stages of construction. The logistics coordination has therefore been outsourced by the client to a TPL provider, who oversees the overall logistics of the area and produced the Construction Logistics Plan (CLP) during the early stages. In order to better control the inbound transport, the TPL provider acquired a rented land area beside the project site to serve as a checkpoint. The site manager at Project B explains that the responsibility of the work environment (BAS-U) is divided between the TPL provider´s project manager and themself. While the site manager is responsible for the area within the perimeters of their site, the TPL project manager is responsible for the safety of the streets and passageways surrounding it. Additionally, part of the production planning has to be performed jointly with the contractor erecting an adjacent building, as there are only 12 meters between the facades. Their time plans have to be adapted to minimize disturbances to one another, as well as considering the groundwork that a third actor is conducting in the street in between.

4.4.2 Digital logistics tools at Project B

Project B uses four of the six digital tools identified in the study. Two of the tools, Myloc and Trello, are used exclusively for logistics purposes (see Table 4.3). Trello is not used by BRA in this project but rather by the external logistics coordinator hired by the client to ensure good cooperation between the projects.

Table 4.3: Digital tools utilized for logistics activities in Project B.

Tool	Application for CLM	Responsible actor	Users of tools
MyLoc	Delivery planning and control	External logistics coordinator (TPL)	Logistics group Block managers BRA supervisors Foremen of subcontractors
Trello	Task distribution	External logistics coordinator (TPL)	External logistics coordinator Material distribution subcontractors
Infobric	Digital safety and environment inspection round protocols	Supervisor responsible for inspections	Supervisors Representatives of subcontractors on site
Dalux	Task distribution through WAPs	Supervisor	All relevant actors

Project B utilizes the digital DMS MyLoc Construction as its main digital logistics solution. The BRA logistics supervisor receives booking requests through the system from fellow supervisors and subcontractors and decides whether to accept them. The request is then passed on to the TPL provider, who has the last word if there is a risk of clashes or congestion by the gates because of other project deliveries (see Figure 4.10 below). Bookers can request machinery for unloading and/or carry-in services from the TPL provider to locations inside the building specified on a WAP. The TPL project manager utilizes Trello to distribute material handling tasks among their own workers, unrelated to the activities of BRA staff. The WAPs are in turn created in Dalux by the supervisor from BRA. Infobric is used for environmental and safety inspection rounds, in the same fashion as Project A. The supervisor estimates the number of unbooked deliveries to be about 15% of the total weekly deliveries but claims that these often are small materials, which are easier to handle than bigger building components.

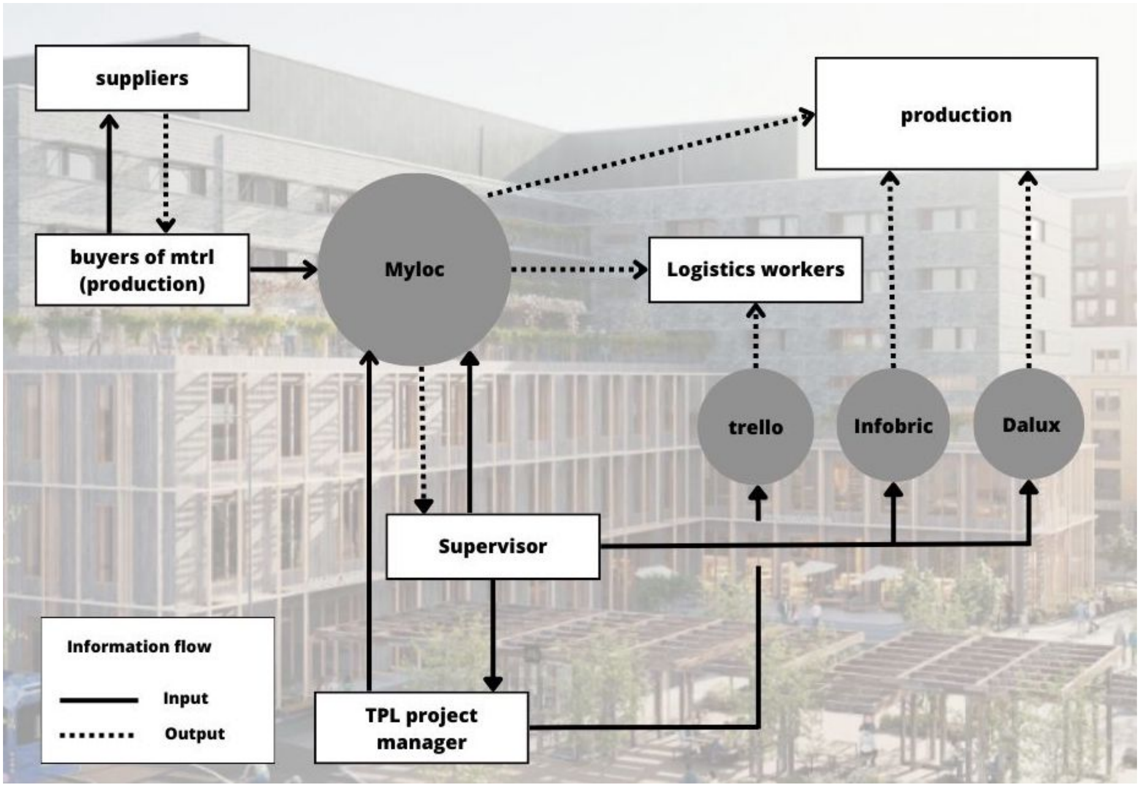

Figure 4.10: The information flow through digital tools for logistics at Project B.

4.5 Project C

The third case project in the empirical study, Project C, is a renovation project consisting of two buildings with a total area of approximately 43 000 square meters. The initial project sum was around 300 million SEK and on average there are around 80 workers, six BRA supervisors, and one site manager on site. BRA is procured as a turnkey contractor in this project and began construction during the spring of 2021.

Soon after, both preexisting buildings were stripped down to the frame. The focus has since then been shifted to interior renovation, frame complements, replacement of the façade, and reuse of old materials such as doors, ceilings, and floor materials. The two nine-story and five-story buildings include office floors, restaurant spaces, and a spa. Situated on the ground floor of one of the buildings is a large grocery store. BRA conducts construction both beneath and above the store and is bound by contract not to disturb the store´s operations. The contract includes renovation to a certain agreed-upon standard, and as such any future adaptation for tenants is handled as an addition. Located in central Gothenburg, it is in direct connection to busy car and pedestrian areas, schools, and residential buildings. Some of the closest roads leading to the project are of cobblestone, which results in higher regulations concerning the weight of delivery trucks and allowed traffic to and from the building site. In Figure 4.11 the centrality of the project and the limited available space around the building footprint can be seen. Furthermore, the construction of the underground train station Haga is ongoing just next to the building site, making the street in between the projects a shared space. This requires extensive coordination and cooperation between the projects.

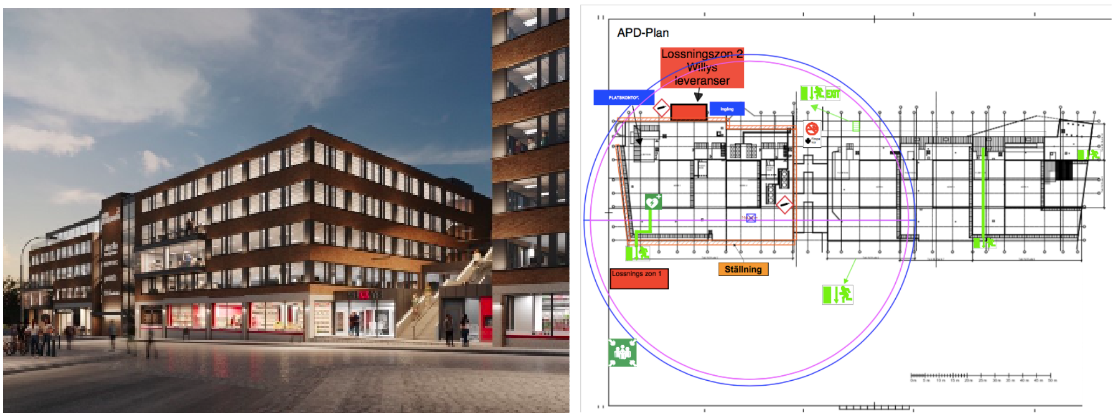

Figure 4.11: Project C: Digital rendering of the building (left) and WAP of the construction site (right). Images provided by BRA.

4.5.1 Logistics organization at Project C

The responsibility of managing all logistical activities related to deliveries and handling of materials at this project is assigned to one BRA supervisor. This was motivated by the intent to create a distinct channel of logistical information and more efficient coordination on the building site, as opposed to sharing the responsibility across the whole site management team. The supervisor estimates that around 50% of their time is spent on managing the construction logistics during an average working day. There is an unwritten agreement on site that those who wish to bring in the material should run it by the supervisor first so that they can plan the crane´s activities. Yet, they state that 30-40% of the deliveries are unknown to them upon arrival and emphasized that they often experience difficult situations with double bookings. The majority of these unplanned deliveries are bound to subcontractors at the site. While most building materials arrive with crane trucks and can be unloaded from the vehicle without the tower crane, the limited space for storage outside requires relocation of the material with the tower crane, nonetheless. When such situations occur, it is up to the supervisor to prioritize between planned and unplanned crane activities to minimize disturbance to the production flow.

There is just enough space for one heavy delivery vehicle at a time. The supervisor in charge of logistics state that they have 2-3 deliveries of building materials per week, as well as 2-3 deliveries booked by subcontractors. BRA´s only means of unloading heavy materials is one tower crane and access to the building is limited. These circumstances obstruct material flows and make receiving deliveries and handling materials more difficult. As there is no available outdoor space for full-size waste containers, all waste is handled through 600-liter bins on wheels inside the buildings. Between 30 and 40 of these bins are kept in a designated area inside the building and retrieved by a waste management entrepreneur once a week. Inside the buildings, there is an abundance of open space. Building materials are stored inside for up to several months in advance to make sure it is available when needed for production. In order to upkeep order on the building site, the site management has hired subcontractors dedicated to housekeeping and carry-in. In addition to this, production is closed for about four days a year by the site manager with the purpose of giving an entire day for subcontractors to focus on clearing the building site. How this logistics method is received by the subcontractor managers is unclear, as it implies that they will not be paid for these labor hours.

4.5.2 Digital logistics tools at Project C

There is no use of digital tools in order to support the delivery planning at Project C. Instead, the supervisor manages the delivery planning using pen and paper, resulting in Project C having the least digital maturity out of the case projects. Furthermore, the site manager has no previous experience using digital DMSs, and does not believe it would help them with the production:

"It is different when you are building a house from the ground up. This project is special, we are doing a renovation. Digital systems would not work here."

However, they do use Dalux in the project (see Figure 4.12 below). The supervisor in charge of logistics creates WAPs through the program, and the site manager is positively inclined to use them for visualization during meetings. Furthermore, Infobric is used for inspection rounds. Table 4.4 shows the digital tools used in Project C.

Table 4.4: Digital tools utilized in Project C.

Tool	Application for CLM	Responsible actor	Users of tools
Infobric	Digital safety and environment inspection round protocols	Supervisor responsible for inspections	Supervisors Representatives of subcontractors on site
Dalux	Showcases WAPs	Supervisors	All actors on site

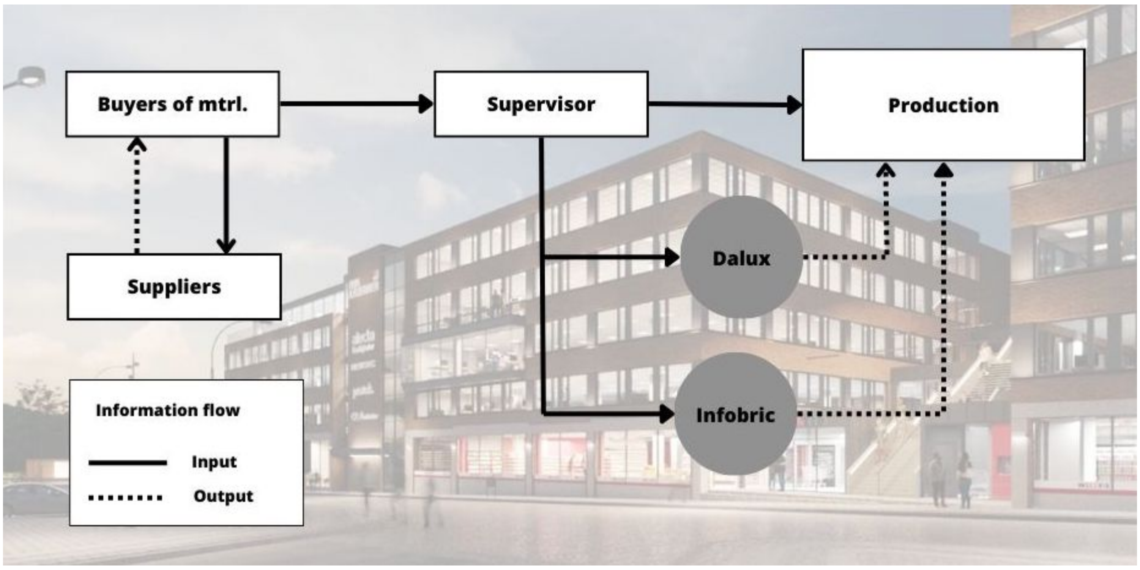

Figure 4.12: The information flow through digital tools for logistics at Project C.

4.6 Usability of digital tools in construction logistics

The general opinion found in the empirical results is that digital tools aid the logistics management and perseverance of logistic activities, much due to the simplification of information sharing within the project and maintaining clear channels of communication. Digital tools, although costly in terms of time for administration, reduce the risks of miscommunications and solidify the goal of the logistics organization. The digital tools used in the case projects all relate to this through three different categories: digital management systems (DMS), task distribution systems, and building information modeling (BIM).

4.6.1 Delivery management systems

Keeping sufficient foresight and planning is crucial for the success of the project. Insufficient planning still is one of the main issues within the production phase, which correlates with lacking communication between the actors onsite. Keeping some type of delivery schedule through a DMS is claimed to be absolutely necessary by several respondents from Projects A & B, as this clarifies and coordinates the planned activities within the construction process. The site manager from Project B connects all activities that need to be managed to the delivery schedule, as the timing of material deliveries influences the whole process from unloading to assembly. The tools used for scheduling deliveries differed in each case project, implying that there is no standardized procedure within BRA. The reason that different types of DMSs are used within the same company is seemingly due to the varying needs of the case projects as well as the previous experiences of, most importantly, the site managers.

At Project A, Lognet is used as a DMS by the logistics management to manage the subcontractors' deliveries. Both the logistics manager and leader believe Lognet to be sufficient enough for the needs of the project and contribute to the construction productivity. They perceive that Lognet provides a better overview of the project's activities and offers a visual context to its users. The system was introduced to Project A about a year into the production phase and was chosen over Myloc mainly because of the lower pricing. The logistics manager states that the implementation required some work and that it took time before the advantages of using Lognet were recognized by the entire workforce. It is also noted that the DMS requires labor hours since adding activities and following up needs to be done manually, which thereof becomes an indirect cost tied to the system. The benefit of gaining reliable statistics about CO_2 emissions and the number of transports per gross total area (GTA) is also dependent on someone adding this data into the system. This is not done in Project A, which results in a loss of data for evaluation regarding delivery times and streamlined turnaround times. The TPL logistics specialist highlights the possibility of evaluation as an important feature of the system since 50% of all deliveries arrive during 7-9 in the morning if not managed according to their statistics. There is a significant opportunity for improvement within this area according to them and the block manager at Project A mentions that these statistics should be provided by the logistics team.

A general criticism against Lognet that constitute a setback in its usability is the fact that the system is website-based. Because of this, respondents involved in Project A state that one must check for updates continuously on the website but would rather have an app-based system that gives notifications when there have been any updates. Furthermore, navigating the Lognet-website on phone devices is difficult, so the subcontractors are less keen to enter delivery bookings into the system while out on site. Another reoccurring criticism is the layout, as many perceive it to be rectangular and outdated. It is furthermore wished for Lognet to have a picture feature and to be connected to the WAP through Dalux, for example. However, it is at the same time highlighted that the simple layout of the program contributes to its usability and contribution to construction productivity. The site manager at Project A points out that digital DMSs more often than not are filled with an abundance of features that are not needed, which makes them seem more complex to new users. In this sense, the simplicity of Lognet is appreciated.

Project A also utilizes Qlocx, which can be interpreted as a kind of DMS, since it automates the receiving of smaller packages. Qlocx is perceived as simple to use and contributes to productivity as it liberates supervisors from distractions accompanying receiving deliveries. The general opinion of using QLocx seemed uniformly positive, and the block manager claims that:

"Qlocx is not really something you use; you just get notifications from it and your stuff is there. It works great."

However, the logistics manager of Project A is hesitant as to whether the time-saving statistics obtained from the app are overstated, as they claim that 20 minutes is a high estimate for the time it takes a supervisor to receive small packages. On the contrary, the supervisor from Project C believed that it is a reasonable estimate as this time included answering their phone, guiding and meeting up with them, and getting back into performing the task that they were disrupted from.

In Project B, Myloc is used as a DMS. Because of the composition of projects in the development area, the TPL project manager chose Myloc as a DMS for all projects involved in order to strengthen the connectivity in-between the projects. Myloc provides more information than Lognet, which transfers to a more complex layout of the program. The value of Myloc seen in Project B is much due to this complexity as more comprehensive information sharing about deliveries is needed for the project in regard to its checkpoint setup. Supervisors at Project B and surrounding projects are able to use Myloc to see which received materials are stored within the checkpoint and order final delivery to the building site. However, all relevant features of the DMS are not used fully. For example, the feature of printing out labels that show a package's placement on the construction site is not utilized. The TPL project manager believes that this is because of the high-stress levels in the project that make site management less motivated to explore the possibilities of the system. Even though the general view of Myloc is positive, the TPL project manager states that the higher costs of the system make many contractors less keen to implement it into the production process.

In Project C, no digital DMS is utilized to streamline the planning of deliveries. When the supervisor with logistics responsibilities entered the project, they expressed concern over their ability to coordinate communication between the subcontractors, as there is a lack of understanding and collaboration between the different actors on site. In an effort to schedule the crane activities, they attempted to implement an analog whiteboard system where subcontractors and work managers could book time slots and resources for unloading deliveries or moving materials, for example using the tower crane. This system only held up during a limited time period, however, since subcontractors are reluctant to leave their work areas within the building to travel to the management office and add their information needed. The supervisor quickly realized that the system was lacking, as bookings gradually became unnecessary long. Activities that required 30 minutes of crane time were eventually booked for up to half a day, creating long waiting times when the crane was in fact available for other jobs. As the subcontractors reached the same realization, a surge of phone calls to the crane operator occurred by people trying to circumvent the system, rendering it useless. Because of this, the supervisor coordinates deliveries traditionally through pen and paper, phone calls, and emails.

4.6.2 Task distribution systems

Task distribution systems aim to promote better communication and can be the foundation for effective succession within the project. Both Trello and Infrobric are used as platforms for delegation and information sharing on the building sites. When asked about the usability of these task distribution systems, most respondents show a positive view of the tools. For the respondents who have implemented Trello into their everyday work process, the tool constitutes an important asset in their communication with subcontractors. Both the logistics manager and logistics leader on Project A prefer Trello as a way of communication, as its layout significantly simplifies the process of tracking distributed tasks as opposed to the traditional communication channels of emails and phone calls. It also reduces the hours needed for controlling activities on the building site, as they no longer are required to do this physically, but rather on the app. The logistics manager at Project A also mentions that the implementation of Trello was a rather quick process. Partly because of its simple layout, but mostly since they only share the tool with the staff within the logistics team. However, the logistics leader pointed out that like with any other communication channel misunderstandings occasionally occur. Language barriers are an existing problem, as many of the subcontractors hired use foreign manpower that does not master Swedish or English completely. This sometimes makes the task distribution via the text feature difficult, although the possibility of adding pictures on the relevant floor plan and material largely relieves this issue. The overall opinion was that Trello is a simple tool to use, fit for smaller groups such as the logistics team on Project A, and most respondents state that they would bring Trello to future projects as well.

Infobric, which is used in all case projects, is mainly perceived as a simple appliance by the respondents. The logistics leader at Project A who had previous experiences of conducting the inspection rounds analogously, finds the digitalization of the process to streamline the inspection rounds profoundly. Both concerning the process itself, the division of the tasks, as well as the control of their completion. However, it is believed that the human factor plays a big role in the success of using Infobric, as management still has to pursue subcontractors several times in order for them to follow up on their assigned remarks. This is seemingly related to the general attitude within construction towards new work methods and digital tools. One aspect that is identified as missing in Infobric is a collaboration feature that makes it possible for several devices to upload remarks at the same time. Currently, only one person can put in notes, which slows down the process of conducting the inspection round.

4.6.3 Building information modelling

Dalux is used in all case projects as a way to digitally showcase WAPs and relevant information. The project WAPs can be accessed in Dalux by any actor involved. In a logistics sense, Dalux is mainly used to access the floor plans, taking advantage of its 3D views to plan the carry-in of hefty construction components and materials. The WAPs in the different case projects vary in complexity and detail, which correlates with the extent of Construction Logistics Management (CLM) at each project. Dalux is also used as a communication channel for core activities as the feature of adding work assignments in the floor plan for different subcontractors is utilized in Project A. It simplifies the process of allocating and tracking tasks as well as monitoring the succession of different parts of the project.

4.7 Usability of different logistics setups

The use of logistics setups differs between the case projects. When exploring the utilization of construction consolidated centers (CCCs), checkpoints, third-party logistics (TPL), and just-in-time (JIT) some of the respondents were unfamiliar with these methods and resources to be used in the logistics setup. However, this could in some circumstances be due to a lack of terminology rather than lacking knowledge of the setups. The results identify that the incorporation of the logistics setups into the production process should mainly be decided on the need for each project. Having these logistics setups in place does not necessarily imply a more optimal production process.

4.7.1 Construction consolidation centers and checkpoints

The logistics setup ’checkpoint’ is according to the logistics specialist largely the same thing as a CCC, with the main difference that a checkpoint is located on or adjacent to the construction site and is managed by the contractor or a TPL provider. In Project B, materials bound for all the projects that are suitable for outdoor storage arrive at their checkpoint when the projects are unable to receive the materials directly. This setup is perceived as well-functioning as all projects active in the development area have designated areas within the checkpoint, which is managed by the TPL project leader. In Project B, the setup is beneficial as it is easy to follow up through the Myloc app and allows a higher level of JIT and more space on the building site for unloading of deliveries, .

CCCs were not utilized in any of the case projects. However, Project A had previously been exploring opportunities of utilizing a CCC for larger building components such as reinforcement bars, according to the site manager. Despite the gain of having fewer materials stored onsite, they came to the conclusion that the costs of a consolidation center in proximity to the construction site, together with the costs of transport to site were not economically defensible. On the contrary, the TPL project leader, believes that the project would benefit from a CCC and that the costs following the setup could have been recovered through the increased productivity it would bring.

4.7.2 Third party logistics in the case projects

Only Project B fully utilizes the service of a TPL provider, in the sense that the TPL provider is hired by the client and has the utmost responsibility for the logistics. This set up was initiated by the client as they saw a need for a comprehensive logistics organization within the development area, which requires a leading actor dedicated to logistics planning and coordination. Furthermore, additional TPL services such as on site material handling increases the level of efficiency for the area as a whole. The consequences of using a TPL set up are, according to the TPL logistics specialist, highly beneficial to a project’s productivity. They believe that having an expert on the CLM and CLP within the production phase contributes to a more centralized and effective logistics organization since they have access to data from previous projects. This allows them to, for example, estimate the number of deliveries at different phases of the project or transports per GTA in order to properly dimension the logistics onsite in regard to the relevant project-based variables.

The logistics manager from AF had former experience with TPLs from a supervisor's perspective. Their opinion of the setup was positive, as it allowed them to fully let the logistics activities go from their work responsibilities and focus on the succession of the production. The calculation engineer from Tornstaden emphasized that the TPL setup never had been tried out within their company, since they have not been able to make it fit into the budget when performing calculations for a tender. They state that the TPL fees often are too costly compared to other solutions, and thereby could jeopardize their chances to win the procurement contract.

The concept of having certain employees dedicated to only construction logistics is mentioned by several respondents as the most important reason why TPL contributes to productivity on the construction site. Even though only Project B used TPL as a logistics setup, all case projects have subcontractors in place who only handle non-core activities. In projects as large as Project A, the economic consequences of an inadequate logistics organization can be vast. The monthly turnover of Project A is as large as the entire project cost of many of BRA´s smaller projects. With over 20 white-collar workers in the site management, there needs to be a dedicated logistics group led by a logistics manager with the authority needed to maintain control and efficiency, the department manager claimed. It is estimated by the department manager responsible for Project A that a project cost of at least 250 million SEK is the threshold of when it is lucrative to use dedicated logistics staff on site. Any project with a budget below that number cannot carry the cost of full-time logistics staff, they argue. If it is too costly to have a logistics organization onsite, they might utilize a part-time service from a TPL, or handle the logistics as part of the production tasks. One of the employees on Project A contradicts this statement, as they thought the project sum to be unimportant to the choice of having a logistics dedicated team or person. This is agreed on by the supervisor from Project B, who states:

"You need people who do not deal with production. Otherwise, it would be like placing a nurse at the front desk of a hospital, everyone will call on her for help. There would not be anyone sitting at the front desk. But the front desk needs to be managed, or the whole operation would fail. That is how I utilize Bimensions[the TPL provider]*. That is the ideology."*

The site manager of Project B states, in a similar way:

"[...] *one must realize that it is better for an installer to install eight hours a day, and for a carpenter to build eight hours a day. Material handlers are more efficient at carrying materials. It´s their job. This means that we never need to compromise the time plan, we know that we will be able to perform in time."*

4.7.3 Implications for Just-in-time

JIT is widely known throughout the case projects as an optional logistics setup, as all projects use JIT for at least some of the material deliveries. However, it became evident that the traditional philosophy of ensuring good workflows by holding stockpiles still is in place, as many respondents prefer this to JIT when possible. If the project-specific conditions allow it, the site managers favor having enough materials for at least a couple of days' production in order to avoid disruptions in the workflow. One of the supervisors mentions that JIT deliveries can become very costly quickly if delayed, as the labor costs of craftsmen are expensive when they are not producing. Several respondents mention that JIT often increases the sensitivity of material flows, which makes them less keen to implement JIT deliveries as a standard. However, the general opinion is that pursuing JIT is crucial for projects that are located centrally or have limited space to unload in order to avoid traffic congestion.

4.8 Organizational preconditions for construction logistics

Several themes are identified in relation to the challenges and benefits of construction logistics. These themes relate to CLM and digitalization in construction logistics. The identified themes are structural barriers, the utilization of construction supply chain management (CSCM) in practice, CLM in the procurement and design phase, as well as work culture and behaviorism in the construction industry.

4.8.1 Structural barriers

The results emphasize a key issue: The traditional view of logistics within the industry as something circumstantial, often underlined by organizational structures. This view still prevails, as a majority of the respondents have experienced or are experiencing that the succession of the production is prioritized to such a degree that support activities in a way are seen as waste streams. Not least during the construction phase, where time is limited and delays constitute an expensive risk for contractors, leading to a certain constant level of stress on the workforce. All respondents with explicit logistics responsibilities in their work agree that efficient construction logistics is important and that it warrants investing significant resources in large projects. However, many of them claim to have been met with resistance due to the fear of stopping production and a lacking understanding of what construction logistics include and can result in. This resistance seems most prominent amongst in-house actors and occurs primarily upon implementing logistics into ongoing projects.

According to the experience of one of the logistics managers, such resistance often stem from higher up in the contractor hierarchy, amongst the individuals that hold the utmost responsibilities within the project. The logistics manager adds that there is less resistance to be met amongst site managers, who are more involved in the activities taking place on the building site. This claim is further emphasized by the finding that of two of the site managers have perceived some degree of opposition from their superiors when trying to implement or introduce new measures to manage the logistics. They often feel the need to persuade their superiors as well as the client in order to get them to believe in the potential gains and see the need for investment in construction logistics. This is typically not due to a lack of trust in the suggestions, but more due to a general unwillingness to invest capital in something whose effects are unknown. All of the respondents with logistics responsibilities agree that having a site manager that supports investment in CLM and believes in the benefits is essential, because of the role and influence the site manager holds as they make all the decisions and have economic responsibility in the production phase. However, it was highlighted that the site manager's attitude towards CLM and digital tools will have some level of effect on how these are perceived by other actors involved in the project. All of the site managers agree that strong leadership and setting clear demands for the workforce to follow are crucial to reach efficient logistics on the building site, but they had differing views on digital tools as a means to achieve this.

The results further emphasize the importance of giving the logistician a distinct role in the site organization to clarify their mandate over other actors' activities on the building site. In Project A, the logistics manager´s authority formally exceeds that of the supervisors in order to coordinate the material flows efficiently. This hierarchy was initiated by the site manager on the project, as they believed it to be crucial to solidify the importance of logistics amongst the production workers and management. The decision was met with some resistance mainly from the supervisors on site, and a lot of work was needed on the site manager's part in order to gain acceptance from the other actors surrounding the logistics team's mandate and the potential gains of CLM. The logistics manager from AF wants to take the logistics team's mandate a step further and wished to one day have the mandate over even the site manager as a logistician. According to their experience, this would be helpful to keep CLM within the project, as it commonly becomes less prioritized when pressures and stress levels increase:

"When the costs are rising or we are met with difficulties within the production, the project leaders make cuts in the budget. As soon as this occurs, logistics is always the first thing to go. We go back to our traditional ways of working when we get scared".

It was further found that the freedom given to the logistician in the production phase is generally limited and that they seldom are given the opportunity to contribute with inputs during the design phase, which possibly could ease the planning required in the production phase.

Results indicate that the need for process development within the industry has pushed construction companies to implement new logistics methods or digital tools. However, this mostly occurs with the prerequisite that there have been good experiences from a previous project within the company. Many explain that the benefits of CLM often are not realized until the material flows and workflows on the building site run more smoothly than before, and even then, it is difficult to accurately state that CLM practices are the reason behind the success. The improvements are instead often attributed to the personality traits of prominent leaders in the projects. In addition to this, the project-based and fragmented nature of the industry contributes to the lack of information-sharing throughout the contractor companies, which limits the knowledge and experiences of CLM setups and tools to certain people. It was often mentioned that the site management team have to “innovate the wheel” during each production take-off due to the absence of standardized method provisions surrounding construction logistics.

4.8.2 Supply chain management in practice

When exploring the utilization of SCM within the case projects it became evident that the general perspective of the actors is that CSCM is included in CLM. However, in practice, the management of the supply chain mainly revolves around the activity of ordering and receiving materials to the building site, as BRA and their subcontractors primarily keep contact with the suppliers closest to the chain in the majority of cases. There is no appearance of a more thorough collaboration or transparent relationship between the projects and their suppliers or waste management providers. A few exceptions of closer relationships with some of the suppliers were identified, through which they are able to store materials that are hard to get on short notice at the suppliers’ storage facility. However, this is a service that BRA pays for when additional storage space is required. There seems to be a certain level of transparency offered by the suppliers, as they notify BRA about future price increases, allowing them to adapt and adjust their delivery schedule and planning if needed. With this as an exception, it was found that SCM within the case projects is relatively limited. As a result, delays and incorrect deliveries frequently occur. It is estimated that about 20%, 15%, and 40% of deliveries arrive unexpectedly in Projects A, B, and C respectively. These are approximated numbers, as documentation of unplanned deliveries is lacking in all cases. This shows that issues related to material deliveries are a considerable barrier to the production process flow and that it is largely due to the supplier’s performance quality.

In Project A, the logistics supervisor states that the turnabout times for deliveries seldom take more than 20 minutes. However, they always plan that the unloading of one truck will take 1-2 hours depending on the type of materials in order to avoid overlaps in the delivery schedule. This routine of adding a margin to the planning is further underlined by one of the site managers:

"If a supplier tells me that the materials I have ordered will arrive in seven weeks, I always expect it to arrive later and plan for it to take ten weeks to be safe."

The lack of structure in the suppliers’ timekeeping seems to be a general issue within the construction industry, to such a degree that it in some cases is somewhat accepted by the site management. However, many respondents state that communication is key and that both subcontractors and suppliers are responsible for having clear demands and expectations, which can improve performance. The block manager underlines that there is a big improvement potential that currently is not utilized in Project A, as the upkeep of tracking delayed deliveries in Lognet would contribute to data that could be utilized to identify issues and reclaim delivery fees, which could motivate suppliers to improve. In both Project A and B, deliveries that arrive early or do not follow regulations - for example, the requirement of a certain label of trucks on the building site of Project A - are generally not let into the building site. However, in Project C the fire-extinguishing attitude is evident as both the site manager and the supervisor admit that they often try to complete the delivery either way. The fact that construction production is unpredictable and inconsistent is often brought up by the respondents, which is why last-minute solutions in some cases are required in order to avoid cost overruns. However, no respondent mentions the improvement potential in offering more transparency on the contractor's side, in order to allow more long-term planning for the suppliers.

4.8.3 Construction logistics during the procurement and design phase

It was found that CLM, if considered at all, often is implemented during the production stage. Many respondents state that the need for organized logistics has to be apparent for the involved actors for it to be invested into.

The calculation engineers from Tornstaden nuanced the results regarding the procurement phase of construction projects. When calculating the overall costs of a project, they make a distinction between net costs, which relate to materials, and operating costs. An overview plan is created, where construction logistics is considered to be included in some of the operating costs. This transfers in needed labor and machinery, and depending on the project, rent for land outside the building site for material inventory or unloading of trucks. Similarly, there is no capital dedicated to only logistics in either of the case projects, as it is included in other operating costs. This way of calculating does not translate well in reality as the budget seldom considers non-core activities in enough detail, such as labor for installing safety railings, building ramps, or cleaning. Yet, this way of calculating makes sense during the procurement since costs for the kind of formerly mentioned activities are difficult to estimate and the contractor generally needs to provide the lowest possible costs in order to get the contract. However, this contributes to the sense that logistics "can come later", according to the logistics manager from PEAB, and only postpones the costs to a later stage. They believe that it would be beneficial for logisticians to be involved in at least the design phase to contribute with inputs in order to create a standard or an outline for the logistics organization before the production starts. According to them, this could result in a more detailed logistics plan and decrease the stress during the construction phase.

In Project A, the logistics planning was initiated in the design phase as the carry-in of bigger materials and exportation of machinery was considered when creating the time plan for the assembly of walls. Additionally, it was the only case project to distinguish between material and transportation costs in two different accounts.

However, the installment of the logistics organization and the use of digital tools was not properly in place until about a year into the production phase.

4.8.4 Work culture and behaviorism

Behavioral patterns and conservative cultures within construction are often identified as significant barriers that inhibit the overall efficiency of construction logistics. Whether organizational culture or behavior constituted the biggest issue differs among the respondents. While the logistics manager from AF believes the homogeneous workforce within the construction industry to be the reason behind the issue, one of the site managers considers there to be a clear difference in attitude towards new work processes between younger and older employees. The site manager has furthermore found that it often is especially difficult for people to accept the concept of letting certain work tasks go to another actor dedicated to construction logistics, as it can give a sense of decreased control. This statement echoes throughout the results, as there seems to be a general lack of trust in the process, especially amongst supervisors within the industry. The results point to the lack of concrete evidence as a reason for resistance occurring in-house, since it is practically impossible for contractors to accurately measure the potential monetary gains of investments in CLM. Some mention that this common phenomenon might be due to the nature of the supervisor's role, as they usually have to manage a broad spectrum of tasks and deadlines. They state that because of this, logistics managers and leaders often have to act as police amongst their colleagues on the building site, which along with the high-stress levels of construction production creates an unpredictable environment for them to implement new work processes successfully.

The stressful nature of construction production is brought up many times during the empirical study as this, according to some of the respondents, shapes the work culture within the industry. The logistics manager from AF mentions that there is prestige within the industry in being the problem solver on the building site. According to their experience, this sometimes makes supervisors who solve crises in production more appreciated than supervisors who plan their activities carefully and thereby avoid crises altogether. The constant changeability of construction projects is an important factor, and this common understanding of the project's nature makes many actors involved in production less prone to plan their work ahead of time and focus on ad hoc problem-solving instead. However, the logistics manager claims that the difference between problem-solving, and last-minute fire extinguishing often becomes very small which then results in delays or higher costs for the project:

"Many people think that planning is unnecessary as everything will change anyways. According to my experience, if I make plans for 100% about 80% will go as planned."

This antithetical view on planning is mentioned by several logisticians as a common attitude within production and part of the traditional construction culture. Construction logistics is something that "solves itself" and consequently, spending extensive time on logistics planning and management is seen as ridiculous.

4.9 The values of a dedicated logistics organization

Even though the general attitude towards construction logistics within the industry might be less than favorable, the results do not identify any negative remarks about CLM as a way of streamlining the production chain. However, the experiences and viewpoints vary on how CLM and the different methods included actually contribute to construction production in practice.

The main challenge of CLM is the need for motivation during the production stage. According to the block manager, sufficient knowledge of new methods is required in order to not only implement CLM but to maintain the logistic structure throughout the project´s duration as well. There is potential for improvement in how management conveys new methods into production, and communication needs to be improved to reach a greater effect of CLM. The earlier mentioned absence of beneficial monetary evidence of CLM is further adding to the lack of motivation to work with logistics more comprehensively within the industry. The results imply there are a lot of hidden costs which are difficult to accurately measure, but may be reduced by keeping a dedicated logistics organization in the production. However, the uncertainty in pinpointing these costs constitutes a huge barrier to advancing CLM. Although this is the case within the industry, results indicate the benefits of CLM to also be of intangible nature. The block manager from Project A states that:

"If we did not have our logistics team in place, more supervisors would be required to manage all the deliveries and material flows on site. Either way, the service needs to be handled. The only difference is that we now have specific people dedicated to logistics, giving us a better view of the overall picture".

The decrease in the managers' workload and stress level is mentioned by several respondents as a considerable potential benefit of having CLM and a logistician on the building site. They anticipated that if the planning of deliveries and carry-in is managed by a logistics manager, supervisors will have more time to focus on their area of responsibility. According to the majority, CLM accompanied by, for example, subcontractors explicit for carry-in, makes it possible for different actors to spend their time doing what they are good at. Thereby increasing efficiency. Some respondents, however, argue it to be more economically beneficial to let the craftsmen handle the carry-in of their own material. This is because the efficiency of subcontractors that only spend their time carrying materials and cleaning the building site sometimes is quite low and strongly dependent on the people involved.

Further identified benefits of increased CLM are fewer collisions between delivery and production activity schedules. Planning becomes more obvious to site management when there is a logistics manager or a logistics team assigned to the overall coordination of the site management's activities. This reduces delays in construction caused by miscommunication. According to the supervisor at Project B, the lack of a logistics organization often results in a "first come first served" attitude on the building site. This often leads to the need for change in later stages, which ultimately results in additional fees by the subcontractors for alterations and additional work that should be paid for by the main contractor.

Another soft value that is mentioned is the advantages that come with having a structured and tidy work environment, which relates to the health and safety of the employees. Generally, the respondents agree that the work environment improves with an efficient logistics organization. The overall stress level within the production phase decreases as supervisors are not required to stretch their attention as broadly, which also reduces mistakes. The logistics leader from Project A points to their low number of reported accidents on the building site (about 20 small-scale injuries) as a profit of the order and routines they maintain as part of their logistics organization. During the empirical study, it became evident that this entails a big responsibility for the logistics manager or logistics team. Several respondents claim that the logistician needs to put high demands on their colleagues and that they need to be rather particular in following up on other employees' tasks, especially at the beginning of the logistics organization within the project. However, the logistics leader believes that although a lot of work is required in order to implement and preserve logistical structures, it is an investment that gives the opportunity for the demands on health and safety to increase as the standards become more obvious to the workforce. On a related note, many also mention the benefits regarding the environmental aspects of construction projects, since sufficient logistics management simplifies the process of keeping track of the impacts of different construction activities and deliveries. This is highly relevant, as environmental requirements for construction have gradually become more prioritized by both clients and authorities. According to several respondents, there are big opportunities in improving the environmental impact of a project with the streamlined management of material deliveries, as transport constitutes a big part of the overall emissions and pollutants a construction project generates.

4.10 Project-related preconditions for the planning of well-functioning logistics

When asked what the most influential precondition for the planning of a well-functioning logistics organization is, the respondents have very different and sometimes contradictory lines of reasoning. They were given six project features to consider: Gross area, project sum, access to the site, available space for unloading, client demands, and storage capacity on site. Their answers were interpreted and given a value of 0-3, with 0 representing "irrelevant for logistics", and 3 representing "most influential for logistics". If the respondent did not consider a feature at all, it has not been given a value. The results, compiled below in Table 4.5, show a large variance for each feature. All features but two (access to the site and available space for unloading) are ranked every value from irrelevant to most influential by different respondents. Additionally, some of the features are considered to be interlinked to varying degrees. This shows a lack of consensus as to what variables to consider when planning for an efficient logistics setup.

Table 4.5: Importance of each project-based parameter according to the actors.

Variables	GTA	Project sum	Access to the building site	Available area outside the building footprint	Client's requirements	Available storage space
Respondents						
1	1	2	3	2	2	1
2	1	2	3	3	3	1
3	0	0	2	3	1	2
4	2	1	3	3	2	3
5	1	0	0	3	3	2
6	1	1	-	3	2	3
7	-	3	2	2	0	3
8	0	0	2	3	-	1
9	1	0	3	3	1	2
10	0	0	3	2	1	0
11	2	2	3	3	1	-
12	1	1	3	2	1	0
13	0	0	3	2	0	1
14	1	2	2	1	3	3
15	-	2	3	3	2	-
16	0	1	3	2	1	2
Average value	0.79	1.06	2.53	2.50	1.53	1.71

4.10.1 GTA and the project's sum

The site manager from Project A emphasizes the importance of the project sum. In their mind, the budget is the number one deciding factor for the number of resources that could be allocated to logistics functions in a project, and the larger the total sum, the larger the share available for investment in logistics. The site manager from Project B, however, claims the project sum to be a neglectable aspect, and that it all rather comes down to the physical attributes on and around the site. The TPL project manager reasons similarly and states that they are not interested in offering their TPL services to projects below 20 000 sqm. He expressed:

"The gross area is a more important factor to consider. The cost or budget of a project can be misleading. Higher cost often means that you have a fancy view, impressive courtyards, or golden railings. That doesn´t say much for logistics compared to the gross area."

Some respondents also link gross area to the area of the property, claiming that it matters whether you build a small building on a large property, or a large building on a small property, as the latter has considerable implications for the factors of storage space, space for unloading and access to the site. The logistics specialist from Svensk Bygglogistik claims that the size and budget of a project matter very little for the possibility of reaping the benefits of using a digital delivery management system:

"If you view logistics as a measure of efficiency, then the size and cost of the project do not matter."

4.10.2 Access to the building site and space available for unloading

The available area outside the building footprint and access to the site stand out from the other features with the highest average values of 2.53 and 2.50 respectively. The supervisor from Project C ranks them both as the most influential factors. This is motivated by the conditions at their site, where access-related issues are creating daily challenges and outdoor space is extremely limited, allowing at best one vehicle at a time. All other actors except one each agree that these features are important and award them with a value of at least 2, making them the only factors where a strong consensus among respondents on their influence is found.

The logistics manager at Project A emphasized that even though they had well over 200 deliveries a day at one point early in the framing stage, the logistics is harder to coordinate currently when the project is around 70% completed and the number of deliveries is closer to 40 per week. It is not the number of deliveries that matters the most, they claim, but the fact that the available space both in and out of the building has shrunken over time. The number of access gates and roads has been reduced to a third, along with the unloading zones and the number of cranes. This “slimming” of the site is due to increased activity at adjacent construction sites and the partial handover of the building to the client. Subsequently, the flow of materials through the unloading zone is the most critical aspect of logistics in the project, as it has become more sensitive to interference.

4.10.3 Clients´ requirements

Most respondents agree that client demands are rather unusual when it comes to construction logistics and others dismissed it as completely irrelevant. Several argue that clients generally focus their attention on time and budget rather than logistical methods while achieving efficient production in terms of time and money can be a result of efficient logistics. Thus, the general view is that client demands usually are not a factor to be considered. There were outliers though, as one respondent claimed client demands are always a top priority and can have large effects on the logistics. Another mentions that the client may place indirect demands on logistics through environmental certifications, like waste management requirements in BREEAM.

4.10.4 Available storage space

Two distinct, opposing opinions emerged on the topic of available storage space. While some argue that more space and buying in bulk is crucial, others believed strongly in the principles of JIT and streamlining. The block manager expresses the former opinion:

”It does not matter how large your site is, there is always a lack of space. You fill up the space you have. But there is big money in keeping large stock on site. Take plasterboard for example, you can save 10-15% by ordering a full vehicle and trailer compared to buying a few packages at a time.”

On the contrary, others (often logisticians) claim that keeping stock on site significantly increases waste streams in terms of unnecessary movement of materials, as well as damages to materials from handling and weather. The TPL project manager emphasizes that material movement is the biggest issue for most projects as it accounts for 30% of logistics costs. They further claim that Project A spent significant effort on moving materials back and forth before implementing their 10-day rule for subcontractor´s stock, and as such could have benefited greatly from utilizing a CCC setup instead. The logistics specialist from Svensk Bygglogistik has a similar view:

"Sometimes it is worse to have vast amounts of space on the worksite since it increases the handling of materials and the risk of damage. You plan less if you have lots of space. If space is limited, good planning becomes a necessity."

5

Discussion

This chapter contains a discussion in line with the analytical framework presented in chapter two. Accordingly, the discussion centers around the aim and research questions, where the benefits and challenges of operational and digital advancement within Construction Logistics Management (CLM) will be examined, as well as the digital advancement's effect on costs, social, and environmental sustainability. Thereafter, the key features of construction projects for the advancement of the logistics organization will be established. Furthermore, identified and implied organizational gaps and structural barriers against the ambition of a streamlined production process will be reviewed.

5.1 The benefits and challenges of advancement in construction logistics

The results point to an ambiguity of whether or not an advancement in construction logistics is beneficial, including which effects can be achieved from such an advancement, or if it even is possible to implement. However, in general, the actors have a positive view on having a construction logistics management (CLM) strategy within the production process, which shows that awareness of the need for construction logistics has been somewhat realized within the construction industry. Yet, this realization only exists to a limited extent, as actors tend to base their stance on and participation in construction logistics from their own perspectives and work situations, which reflects in their opinions of what enhanced construction logistics can bring about. This points to that the actors are mainly concerned about what a potential advancement implies to them individually in relation to their specific work tasks, including potential benefits, while often not considering the contribution of construction logistics to the overall productivity of the project. Consequently, the potential of logistics advancement for productivity gains, which has been identified as one of the main benefits of construction logistics (Janné & Fredriksson, 2022), is not exploited to the extent possible. Thus, the full benefits stemming from investments in CLM in terms of reducing issues and waste streams along the production process are lost, which is an expected result in the absence of properly planned construction logistics (Koskela & Vrijhoef, 2000). Furthermore, the difference in interests between the actors involved in the construction process inhibits efficiency as the actors work towards individual goals rather than a coherent goal, which hampers advancement in construction logistics.

While it could be stated that construction logistics needs to be further incorporated into the overall strategy of BRA to achieve improved production efficiency, one must consider all relevant actors' experiences and demands in order to install a well-functioning logistics organization without disrupting the production flow (Fredriksson et al., 2022). Both the challenges and benefits regarding how CLM is implemented and executed need to be considered as a lessons-learned to improve construction logistics further and simplify the implementation process. Many of the advancement obstacles found in the study were related to common challenges that had been forewarned in the theoretical framework and included four main topics concerning; supply-chain management, implementation of logistics setups and digital tools, as well as institutional preconditions.

5.1.1 Supply chain management

The first common challenge established by the results is the lacking knowledge about the importance of construction supply chain management (CSCM) within the industry. This challenge becomes a significant barrier to the improvement of productivity since investments in CSCM have been detected as essential to optimize the material flows on the building site (Koskela & Vrijhoef, 2000). Instead, the case study presents a trend of the negligence of the off-site activities in the construction process by the involved actors, which results in disruptions in the horizontal process flow shown by delayed or incorrect deliveries (see Figure 2.1). The basis for the lack of CSCM partially lies in the absence of a coherent understanding of what supply chain management (SCM) entails in regard to construction logistics, which has been found to affect inter-organizational relationships and thereof the productivity within the supply chain (Larson & Halldorsson, 2004). The results point to that actors involved in the production phase generally hold a Traditionalist view of SCM (see Figure 2.3), meaning that they interpret CSCM to be a sub-part of construction logistics, thus contributing to an inadequate consideration for the supply chain during the construction process. As a result, the effects appear as generated issues and waste streams, which often become evident first in the production phase where corrections often are challenging to perform as the terms of budget and time have been enforced and thereby are resources that are difficult to shuffle during the production. In addition, posterior problem-solving by the main contractor causes the project to miss out on systematic benefits that earlier involvement is shown to produce (Civic, 2018). Thereby, it could be stated that the lacking involvement in CSCM leads to a loss of opportunities for further improvement of efficiency for BRA, which will be a continuous issue until action for further implementation of CSCM is taken. Furthermore, it has been found that the horizontal process flow is prioritized by the actors only once materials arrive at the building site, while the horizontal flows which occur off-site often are overlooked by the contractors. This becomes especially evident when observing the number of late and incorrect deliveries within the case projects, as delays are common to such an extent within the industry that the general assessment of this phenomenon is that it "just exists", creating an apprehension that it cannot be improved by the actors involved. Thus, the full benefits of having a CSCM organization are yet to be realized by BRA, which constitutes one of the main obstacles to advancement in construction logistics. Consequently, it is applicable to assume that issues such as delays or incorrect orders would not be as much of an influencing factor to the construction process with an improved CSCM, which subsequently would allow better planning of workflows and benefit the production.

In the interface between onsite and off-site logistics, the horizontal process flow is managed differently between the case projects. Partly in the type of DMS used to plan, book, and receive deliveries, but also in how the production management organizes the communication with the suppliers and uses logistics setups to streamline the horizontal process flow. From these differences, the case projects can be categorized into each of the three distinct modes of organizing logistics identified in the theoretical framework (Dubois et al., 2019). Project A holds a strong resemblance with the *onsite coordinated configuration*, which is shown by the highly monitored interface between the onsite and off-site logistics using the digital DMS Lognet that allows them to clarify their delivery schedule to the suppliers. Likewise, Project B's utilization of Myloc grants more profound coordination with the suppliers and the adjacent projects within the development area. In combination with their checkpoint solution, the configuration of the project resembles a light version of the *Supply network coordinated configuration.* Project C's lack of a digital DMS and thereby coordination is in line with the more traditional *De-centralized coordinated configuration.* While the different configurations imply different levels of supply chain involvement, it is stated that they should be tailored to the project's preconditions, meaning that one way of configuring the construction logistics is not better than the other by default (Dubois et al., 2019). However, by looking at the number of unplanned deliveries, it can be stated that there is a need for further development in working methods, as the current modes of organizing the construction logistics, especially in Projects A and C, are not sufficient enough. In Project A, this seems to be due to the absence of following-up incorrect deliveries in the DMS, which consequently leads to unexploited improvement potential in streamlining the supply chain, while in Project C the lack of a digital DMS seems to be the main issue as the preconditions of the projects are too complex for keeping an efficient analog delivery schedule.

Further affecting the success of the logistics configuration in the case projects are the ways of interacting with the suppliers in regard to incorrect deliveries, where Project C is keener to accept deviations than the other projects. This is seemingly a result of the high-stress levels within the project as turning incorrect deliveries down can result in delays for production. However, too much tolerance can inhibit suppliers' improvement in keeping to the delivery schedule and predetermined provisions as it sets low expectations on the suppliers' timekeeping. If the site management refuses access to the building site in case of incorrect deliveries, the supplier either has to correct the issue or wait until the set time if they are early. Combined with a functioning DMS, these actions could lead to lesson-learned for the suppliers and contribute to better involvement by both the site management and suppliers, which in turn, would contribute to a reduction in supply chain-related obstacles to further advance the construction logistics onsite.

Other benefits that follow efficient CSCM is the increased alignment and transparency of the supply network, which has been found to benefit both the contractor and suppliers as it allows more foresight and grants planning of deliveries long-term (Koskela & Vrijhoef, 2000). However, transparency is not necessarily wanted by the contractors, as it was admitted that actors in some cases make just-in-time orders on materials to keep data relating to production planning and budget secret from a competitive point of view. This contradicts research, as it is stated that contractors should work interlinked with their suppliers and clients (Janné & Rudberg, 2017) but could possibly be a result of the construction industry's nature, as contractors are awarded on the premises of low costs and so their suppliers are procured on the very same premises rather than a strategic basis, making the relationships with the suppliers a temporary aspect that might not be viewed as worth the investment. The competitiveness within the industry combined with the lowest cost procurement norm could be a reason why all actors seemingly act in an individual manner. The contractors focus on what they need, who will deliver it, and how much it costs them, which is reasonable considering the high pressures of construction projects. There is an absence of strong enough incitement for the actors to consider which option is the most optimal from the perspective of the overall production chain, even though a broader collaboration throughout the production chain might be more beneficial in the end.

5.1.2 Implementation of logistics setups

When discussing different approaches to logistic setups, both researchers and practitioners believe that the variables of the construction project are the main aspect to consider when choosing which setup should be used. Relevant to the study are the three logistics setups: *construction consolidation centers (CCC)/checkpoints*, *just-in-time (JIT)*, and *third-party logistics (TPL)*, which were implemented into the case projects due to the varying preconditions of each case. Subsequently, actors have found both benefits and challenges following the setups. However, the benefits of each setup are found to be much broader in research than what is recognized by the actors. For example, JIT is utilized to at least some degree in both Projects A, B, and C. Out of the three setups used, this is the most known within the industry and is perceived to be beneficial in projects situated in dense urban areas. However, contractors generally are careful to utilize JIT because of the sensitivity in regard to delayed deliveries (Ballard & Howell, 1995). This is a reasonable logic as JIT involves an increased risk since workflows become more perceptive to delays, which could be related back to the lacking CSCM within the construction industry. Although this is the case, there is a significant opportunity for productivity improvement as it has been found that JIT can contribute to a reduction of circa 15% in the costs of labor and materials (Sullivan et al., 2011). In order to achieve such results, further prioritization in CSCM is required as a successful JIT-delivery method demands a well-functioning off-site horizontal flow. If these two components could be mastered by the BRA, the currently existing hesitation to utilize JIT could be decreased significantly.

The second relevant logistics setup to the study is the solution of CCC or checkpoint. Even though not operated in either of the case projects, using a CCC as a logistics setup is an alternative if the supply chain is not sufficient enough to fully utilize JIT. Except for reducing the risks following JIT deliveries, this approach contributes to further gains related to the environmental impact of construction projects, as co-delivery allows less construction traffic within the city perimeter (Sezer & Fredriksson, 2021a), resulting in less traffic congestion both in the city and onsite, which leads to a decrease in the construction industry's contribution to CO_2-emissions and pollution (Kong et al., 2018). However, the costs of renting and operating a CCC or checkpoint can prevent contractors from engaging in the implementation of the setup within their logistics organization. The potential utilization of setups such as CCCs or checkpoints should be evaluated and decided upon when creating the construction logistics plan (CLP) (Whitlock et al., 2018), prior to production. These logistics setups are not fit to be implemented after the initiation of the production phase has taken place, as monetary resources generally are more restricted. Thus, this can be interpreted as a matter of early logistics planning and revolves around the general resistance to including CLM in the early stages within the construction industry.

Lastly, the third logistics setup is the utilization of TPL services. However, the current logistics operations taking place in the case projects make it relevant to not only analyze the benefits and challenges of using a TPL provider but of having an in-house logistics manager as well. Although one should not forget the precondition's influence on construction logistics, it was found that some principles could be standardized for the development of buildings. For example, the principle of assigning responsibility for onsite logistics to at least one actor in the production phase should be a basic requirement, as it improves the efficiency of information flow in the production process. However, actors sometimes have the comprehension that the project sum is required to be at least an undefined amount of money, in order to properly gain the monetary benefits of hiring staff dedicated to the CLM. On the contrary, it is argued that the labor costs of managers or supervisors dedicated to CLM rather would be transferred and distributed between several actors in the absence of a logistics manager, resulting in a more diluted logistics organization and less efficient management of material flows and workflows. However, the majority of actors agree that a supervisor dedicated to logistics is beneficial in all types of construction projects and that the size of the logistics organization is dependable on the project's preconditions.

Once the need for staff dedicated to construction logistics has been realized, the question is how the logistics organization should be steered. This can be done either by keeping the competence in-house or hiring a TPL. The latter option has been found profitable, as it liberates the contractor from logistics responsibilities and ensures a more dedicated CSCM (Ekeskär & Rudberg, 2022), however, it was found that contractors are keener to keep the construction logistics managed by in-house actors in reality, which possibly could be due to a fear of loss of control or high fees

(Ekeskär & Rudberg, 2022). Because of this, contractors generally favor using TPL providers on a smaller scale, such as hiring them as subcontractors for material handling and housekeeping, or utilizing their digital tools for logistics purposes. This variation of the logistics setup seemed to be sufficient enough in the case projects and offered clear results, as there are monetary and productive benefits of having craftsmen liberated from non-core activities since their labor hours, in general, are more costly for the contractor. This ability to balance different options and their outcomes is crucial in order to achieve optimal results when contemplating the implementation of different logistics setups. The efficiency of this ability stems from the *logistics maturity* of the organization, which encompasses knowledge of different possible setups as well as the different actor's perspectives. Furthermore, it is important for the contractor to consider that the benefits of each logistic setup and digital tool likely will be difficult to measure accurately in terms of cost savings, as it rather is the interplay between the setups and the digital tools that will contribute to the reduction of costs and time-duration in the project.

5.1.3 Implementation of digital tools

The use of digital tools has in general been found to facilitate the efficiency of the logistics organization in construction projects. However, the implementation of new digital systems has been proved to be challenging, which leads to the contractor missing out on the full potential benefits that digital tools can bring to the logistics organization. In terms of the case projects, three distinct levels of digital maturity can be identified. Accordingly, their respective project organizations possess various levels of in-house logistics knowledge, achieving different results in their utilization of digital logistics tools.

The differing results seemingly also depend on the various methods of initiating the utilization of digital tools. In particular, what proved to be important is when and by whom the digital tools are implemented. Project C has not implemented any digital tools exclusively for logistics, even though the supervisor in charge of logistics expresses that they are missing a platform for coordination among subcontractors and deliveries, such as the digital DMSs used in the other cases have proven to provide. However, the implementation of a digital DMS may be challenging to perform now since Project C has come far in its production, as the success of implementing digital tools has been found to largely depend on how early it is introduced. Furthermore, the supervisor would need support from the site manager, and preferably other actors higher in the vertical process flow who are involved in the planning and procurement phase (see Figure 2.1), in order for the implementation to be successful as it involves changing the routines of many involved actors both on and off-site. In Project A, the DMS was implemented during the iterative development of the logistics methods during production and was managed by the in-house logistics manager. Because of the late initiation of implementing Lognet, it took a significant amount of work to gain acceptance and trust in the system from staff on site, and it required constant monitoring by the manager. Had it been implemented earlier as in Project B, where the DMS was stipulated in the CLP prior to the production phase, the acceptance and commitment toward the system might have been higher (Haglund et al., 2022). Since the DMS is monitored by the TPL provider in Project B, less work is left to the site management in the production phase, which possibly contributes to the positive view of the system. However, as a consequence, less knowledge is kept in-house as a resource for future projects.

While DMSs have been found to be the most intricate to implement out of the identified tools, their effects on logistics efficiency are the most profound. The central function of the systems, the bookings in a delivery schedule, constitute an agreed-upon standard for deliveries that demands planning from both suppliers and onsite staff. The study found that the projects who utilize a digital DMS receive substantially fewer incorrect or unplanned deliveries (15-20%) than the one who does not (40%). Unplanned deliveries require ad hoc sourcing of unloading equipment and staff, often causing disturbance to ongoing activities. The agreed-upon rules that a digital system provides make it easier for the site management to maintain consistent planning and control, while the pen-and-paper variety creates room for misunderstandings and unannounced initiatives by subcontractors. In the latter case, the study found a stronger inclination by site management to accept unplanned or incorrect deliveries, promoting a firefighting mentality and thereby less compliance to prior agreements by suppliers, as opposed to the other projects where incorrect deliveries were refused entry to a larger extent. Thus, this study supports the argument that a digital DMS can lead to less congestion and double handling of materials (Whitlock et al., 2018).

Regarding the delivery container Qlocx, which in this study has been categorized as a variety of digital DMS, the implementation process in Project A was very successful. In addition, the digital app interface is perceived as user-friendly and efficient. The fact that it eliminates the need for interaction at the time of delivery is the most appreciated effect, as supervisors would otherwise experience regular interruptions in their work to meet up with couriers. It is worth mentioning that some small goods suppliers have drop-off options for their deliveries even without a container system in place, but the system also keeps the vehicles out of the site completely, which is a significant improvement from a logistics point of view, as building sites with limited outdoor space quickly can suffer congestion if not constantly monitored. Since most deadly accidents in the construction sector are machine and vehicle related (2022), a delivery container is a cheap way to improve the safety and work environment on site. Additionally, it can save management labor costs for projects with more than 30 deliveries/month of small packages. Thereby, delivery containers may increase safety for all urban or tightly configured construction sites, as well as save costs for larger projects with daily deliveries of small goods. However, the system does not promote co-loading or collective ordering, which means that the same number of transport vehicles has to travel between the suppliers and the site, creating emissions of pollutants. Therefore, a delivery container is not necessarily an improvement to environmental sustainability.

Task distribution tools are a means for better communication, which is a highly requested improvement throughout the study. They come with little to no cost and can cut lead times in information chains across large building sites. In Project A, Trello is specifically used for information sharing regarding construction logistics, which the actors involved in the system seem content with. It was however found through observation of the digital tools used within the case projects that similar functions exist in Dalux, as it not only provides WAPs but also functions for task distribution and inspection. As this tool already was implemented in the planning process in all case projects, one could argue that it would be more efficient to utilize the functions included Dalux rather than introducing Trello and Infobric at a later stage. Thereof, fewer systems would be used within Project A, which could contribute to an increased acceptance by the actors involved and reduce the challenge of resistance towards digital tools within the production phase. It may also lower the bar for the required in-house competence if fewer, more comprehensive tools are used in a project. Ultimately, using the same tool for the planning of construction logistics and production is a step towards bridging the gap between the two otherwise separate information flows (Magill et al., 2022) and opens the door for future integration of CLM and CSCM in BIM and 4D BIM as the in-house competence increases over time.

None of the projects have formulated a plan for how to evaluate the performance of their digital tools. Even though the digital tools in general were appreciated by the actors, it may prove difficult for logistics staff to motivate the need for such systems when entering other constellations of colleagues in future projects. Furthermore, the projects that used digital DMSs did not consistently document turnaround times or unbooked deliveries and thereby missed out on obtainable, reliable statistics. This result is in line with research theory, which argues that manual iterations and feedback on the system performances are required to fully achieve the benefits of using them (Civic, 2018). Whether the lack of continuous evaluation is a result of an industry tradition of not saving data remains unclear, but the risk of facing perceptions of uselessness when implementing the tools in future projects due to a lack of proper evaluation was reinforced by the empirical findings.

Previous research attributes the lack of investments in improvements of logistics to the fact that construction projects are not capital intensive (Sullivan et al., 2011) and that the significant investment cost in new technology deters companies (Agarwal et al., 2016). However, the case study shows that the cost of the digital logistics tools themselves is marginal, at least for larger projects, and that the main cost of digital tools is the cost of working hours for logistics staff who will manage and use the tools. This cost is difficult to derive from the budget, as labor hours are bundled into one account for site management, and one for hired staff. In Project A, the logistics group has accumulated significant labor costs, though the account includes all activities attributed to them. To showcase their efficiency, their costs would have to be weighed against the hypothetical alternative of traditional logistics management carried out by supervisors and other actors. How much of this potential saving can be attributed to the aid of digital tools is beyond the scope of this study. However, some of the tools include functions for statistics, which can be used for estimations. Our study points to factors other than the size of the investment as the primary deterring element of implementing new technology for CLM.

5.1.4 Institutional preconditions

The absence of a detailed budget for non-core activities found in the empirical study contributes to a lacking logistics overview within the entire organization, as the CLM often is both planned and implemented during the production phase. Because of the complexity accompanying each construction project, it becomes a challenging task to structure optimal logistics solutions in the production phase, where the budget already has been set and the employees have been accustomed to certain working methods. Supporting this issue are the slim economic margins on which construction projects are operating, which affect the actors' decisions (Civic, 2018), and are especially relevant during current material price increases. Therefore, logistics-related costs often are kept low by avoiding spending time and money within that discipline, while willingness to invest is constrained by the conflicting goals of the decision-makers. This is in line with findings from the study, as efforts to cut costs generally are not made through pushing better support functions, but rather by shrinking them. This is highlighted by several logisticians, who previously have experienced that construction logistics is the first discipline to be slimmed down in the occurrence of economic difficulties, even though that usually is the time when support functions are needed the most. Previous research has found that efficient planning of construction logistics can reduce costs by up to 20% of the total construction costs (Dubois et al., 2019), while the TPL project manager believed it to be up to 30%. Either way, this reduction in costs will not be achieved by cutting the resources available to the logistics team in the long term. However, even though it is counter-productive, this reaction perhaps is reasonable considering the high pressures within the industry.

In line with this challenge of cost-prioritization, the results also highlight the issues of how the benefits of construction logistics are valued by the involved actors. From the results, it is found that leading actors mainly focus on hard values such as costs and time when considering initiating new logistics setups or digital tools. However, almost exclusively softer values such as an improved working environment and reduced environmental impacts are brought up by the actors, which are stated to be less esteemed by leading roles. While pressures to keep costs and time low are highly relevant to all included in a project, some actors experience that investment in logistics disciplines will optimize the construction process. On the contrary, many find the values of such investments hard to estimate. This creates a major barrier to the advancement of construction logistics and is a complex issue within the construction industry that might be difficult to change.

Another major institutional challenge found in the study is the general work culture within the construction industry. Some actors recognize that there is a strong social norm of promoting last-minute problem-solving and fire extinguishing as opposed to planning upcoming work activities in detail, which may be part of the explanation for why the arrangement of preparing the CLP before the initiation of the production phase is not common practice within the industry. Again, the statement about the issues of solving problems as they arise (Fredriksson et al., 2022) becomes relevant in this aspect as well. By comparing Project B to Project C where the logistics maturity is found to be of a lower level, one can assume that last-minute problem-solving decreases productivity and should be avoided if possible by practitioners within the industry.

The last institutional precondition that constitutes a challenge for the advancement of construction logistics is the human factor and accompanying behaviorism, which is not commonly brought up by researchers when discussing construction logistics. However, this proved to be a crucial precondition that not only affects the way construction logistics is perceived and executed but also the efficiency of the overall construction process as well. From the actors, it became evident that construction logistics in general previously has been recognized as a diffuse activity that exists only in the background. When contractors suddenly decide to highlight CLM or CSCM and structure a logistics organization within the project it adds yet another weight to the employees' workload, making them uninterested and less keen to embrace the change. Again, initiating implementation during the production phase has been proven to be unfavorable, as it does not provide the correct preparations for the employees, resulting in in-house resistance. It could be assumed that earlier admission of construction logistics would lead to greater acceptance of new work processes amongst employees and higher efficiency.

5.2 The key features of construction projects

It is found that the construction industry is highly varying and that a project's preconditions influence possibilities and choices made considerably. It also becomes clear that the preconditions for logistics at a project are interconnected, and that there is no sure way to set a standard usage of digital tools or logistics setups based on each parameter individually. However, a standard could be set for the planning process of the construction logistics as many of the steps included in the building process are similar across projects. For example, the excavation of ground materials, assembly of the building framework, and waste disposal are almost always conducted within the production process, making these activities foreseeable and usable as an outline for early logistics planning, even though the details surrounding these activities vary. In order to create a standard for how to plan the logistics, the preconditions of the specific project have to be connected to the planned activities. From the ranking of the importance of different project features, it becomes evident that a general consensus of what the most influencing factors are is lacking within the sector, which could contribute to the absence of standardized planning of CLM and CSCM before the production's initiation.

The fragmented priorities are apparent as opinions differ largely even between actors of the same roles. What could be taken from the results shown in Table 4.5, however, is that actors tend to rank both access to the building site and available space outside the building footprint as the most crucial preconditions that influence the design of the logistics methods and organization. The project's GTA and the project sum are ranked as the least important. However, during more open questioning, costs often are mentioned as a highly directorial factor, showcasing a considerable difference in the respondents' opinions when discussing construction logistics more broadly, which may stem from the change in perspective as construction logistics are put into the context of other surrounding production activities as they are openly discussed. Larger projects tend to require more staff and resources, as well as more space to manage, which results in an increased need for coordination. In Project C, the whiteboard setup used for CLM and CSCM is not sufficient enough for the project's preconditions, and the lacking coordination leads to disruptance and errors in the production flow. This implies that there is a need for the advancement of construction logistics at the project. Thus, the rankings given by the actors can be used to offer some guidance on what BRA should look for in order to simplify the planning and implementation process, which could help in efforts to incorporate construction logistics at an earlier stage. Yet, it should be noted that the variations in the actor's opinions imply uncertainty in how the project parameters should be prioritized and assessed in order to anticipate the required measures, which can contribute to inhibiting the construction logistics advancement at BRA.

The access to the building site and available space are both ranked as important by the actors and are features that are reasonably simple to predict before the initiation of the production phase. If the project is situated in a dense, urban environment, information on these factors gives the possibility to plan relevant logistics setups. In the case of urban projects, the study shows that the utilization of JIT deliveries and a CCC should be considered early on since these solutions are relevant to the preconditions but are hard to initiate during production. Likewise, the appropriateness of different digital tools varies with project preconditions as well as the chosen logistics setups. In the choice of a convenient DMS, the contractor needs to consider what they want to achieve by using it. The utilization of Myloc might be preferred to Lognet if the usage of a CCC or checkpoint solution is planned in order to take advantage of its labeling function. If the project presents less challenging conditions, Lognet might be a more favorable option as it is cheaper and easier to understand. The third highest-ranked factor, available stocking area, is seemingly a divider between the actors. From their statements, one can assume that the available storage space on the building site becomes less influential as the logistics organization develops. If the conditions of the projects allow it, space to store materials may simplify the CLM and CSCM and is an optimal solution if the logistics organization onsite is limited to one or a few logisticians. However, many actors claim that available storage spaces contribute to an increased amount of movement of materials, which consumes resources on the building site. In other words, this precondition's importance depends on the extent of the logistics organization and the goals of the contractor.

6 Conclusions

This chapter presents the conclusions in regard to the aim of the thesis: identifying the benefits and challenges of an increased level of digitalization in construction logistics at BRA. First, conclusions in regard to the research questions are presented. second, based on these conclusions, recommendations for logistics improvement at BRA are suggested. Finally, suggestions for future research are presented.

A pivotal finding of the study is that digitalization will not be enough in itself in order to advance the construction logistics management (CLM) of BRA, since it is the joint benefits between digital tools and logistics strategies that truly provide an opportunity for improving construction productivity. The question is not whether CLM and construction supply chain management (CSCM) improve productivity or not, but rather how they should be implemented to support production. Conclusively, CLM and CSCM should be implemented in relation to the specific production methods used. For digitalization to be a relevant measure, the first step ought to be creating an understanding and a consensus around the impact of different preconditions, as well as the potential benefits of investments in logistics.

6.1 RQ1: Benefits and challenges associated with the advancement of construction logistics

The study shows that advancing construction logistics management (CLM) and Construction Supply Chain Management (CSCM) benefits construction productivity as it helps streamline material flows and workflows. However, the benefits connected to efficiency are hard to measure and specifically tie to the effects of the logistics organization, as they permeate the production activities. In reality, evidence of the benefits can be found in softer values such as increased health and safety of the workforce through an improved work environment. A gain in time efficiency and decreased costs can be seen as an indirect beneficial effect of well-functioning logistics.

The challenges related to advancing the implementation of digital tools for construction logistics within a company are of a more institutional nature. While research shows there are benefits to be reaped from investments in digital tools for logistics, the industry is yet to specify and follow up upon the desired effects that the investments are set to address. This problem can be attributed to the reigning procurement paradigm; it is oftentimes impossible for the contractor to compete with higher overhead costs in the procurement phase, even though investments in construction logistics can result in better overall performance. Since projects are awarded to contractors on these premises, they are also measured by them. Deriving the exact cost or time savings from a single logistics solution has proven very difficult, both in researchers' studies and in practice, since the solutions may produce synergy effects and benefits often are of both tangible and intangible character. For example, using a digital delivery management system (DMS) may lead to tangible benefits such as fewer delays, less congestion onsite, and lower CO_2-emissions. But it could also result in intangible benefits for the production as a whole, such as a cleaner worksite, less stress for supervisors, and better relationships between subcontractors and suppliers. Such benefits are not accurately reflected in current measures of efficiency or performance. Therefore, representative ways of measuring the benefits of digital tools are needed.

Furthermore, the conflicting interests and individualist approach of actors are ever-present obstacles to change, incorporated into the very nature of the construction industry. When logistics planning is introduced during the production phase, it can easily fall into the traditional definition of on-site problem solving, instead of being a strategic asset for increased productivity. The hope of succeeding with the improvement of construction logistics is thereby totally dependent on early implementation and emphasis in the design stage. This creates a solid foundation for digitalization as a means of optimization and streamlining activities.

6.2 RQ2: Potential reduction of construction logistics costs through digital tools

There are two main cost-saving effects of using digital tools for logistics: reduction of labor hours in relation to logistics tasks, and less risk of delays in production.

Utilizing some type of DMS is absolutely essential for efficient CLM and can save significant costs. A key benefit of using digital DMSs is that it leads to fewer unplanned deliveries and increases overall insight into the schedule for all actors involved in the production. Thereby, disturbance to planned logistics activities and production is significantly reduced, which results in lower total costs for the project. It can provide reliable statistics for evaluation but requires manual entries of data for such statistics to be accurate. The structure provided by a schedule prevents miscommunication and automates the sourcing of staff and equipment for unloading. Just how much costs are saved is difficult to specify, as there are indirect savings from the system as well.

A delivery container featuring digital locks and an app interface save labor costs in large projects. That is, the monthly cost of the system is covered by the labor costs of receiving approximately 30 deliveries per month. Furthermore, the improvements to the work environment on site are significant due to the reduction of vehicle traffic within the site perimeters, which could be relevant for projects with fewer deliveries as well. There are further cost-saving effects such as a reduction of delays to production caused by congestion around the unloading zones, but the extent of such savings is beyond the scope of this study.

Task distribution systems allow managers to delegate and follow up without being present, saving time and thereby labor costs for both themselves and workers. Additionally, it is found that digital task distribution systems demand minimal effort in implementation and utilization, which makes the cost-benefit balance favorable.

6.3 RQ3: Contributions to improved sustainability from digitalization of construction logistics

The study shows that digital tools used for logistics purposes simplify the governing of CLM and CSCM processes. An example of this is the difference in unregistered delivery bookings between the case projects where there are clear connections between the digital maturity of the project and the number of unplanned deliveries. As digital tools facilitate the coordination between logistics and production activities, the logistics organization produces better results. The study shows that this can result in fewer transports/BTA, less material waste, less stress for managers, and increased safety on the building site. In other words, digital tools benefit the logistics organization, which in turn can improve the environmental impacts of the project, as well as the work environment on the building site to varying extents.

6.4 RQ4: Key project features in the suggestion of various levels of digital advancement for construction logistics

In conclusion, the study points to a lack of consensus among practitioners as to which project features are the most influential for efficient construction logistics. Features such as project cost and GTA are interrelated but are not necessarily proportional to the need for digital advancement. Physical attributes of the site such as space for unloading and access to the site have the largest impact. Available storage space can be both a blessing and a curse, affecting the need for JIT to avoid unnecessary movement of materials. The interplay of physical site attributes is key for the urgency to monitor deliveries, material handling, and turnaround times through digital tools. Client requirements rarely explicitly concern logistics but can have a significant impact when they do.

However, the tangible and intangible benefits from the utilization of digital tools for logistics may be applicable to projects in different ways. We suggest three different levels of digital advancement be considered when planning the logistics of a project, mapped out in a planning guide in Figure 6.1 below. These logistics levels are based on the findings of this study which relate to projects located in urban contexts where challenging preconditions are more common. However, the benefits of reaching each level can be applied to projects situated outside urban environments as well, as long as the project's preconditions justify the chosen logistics level.

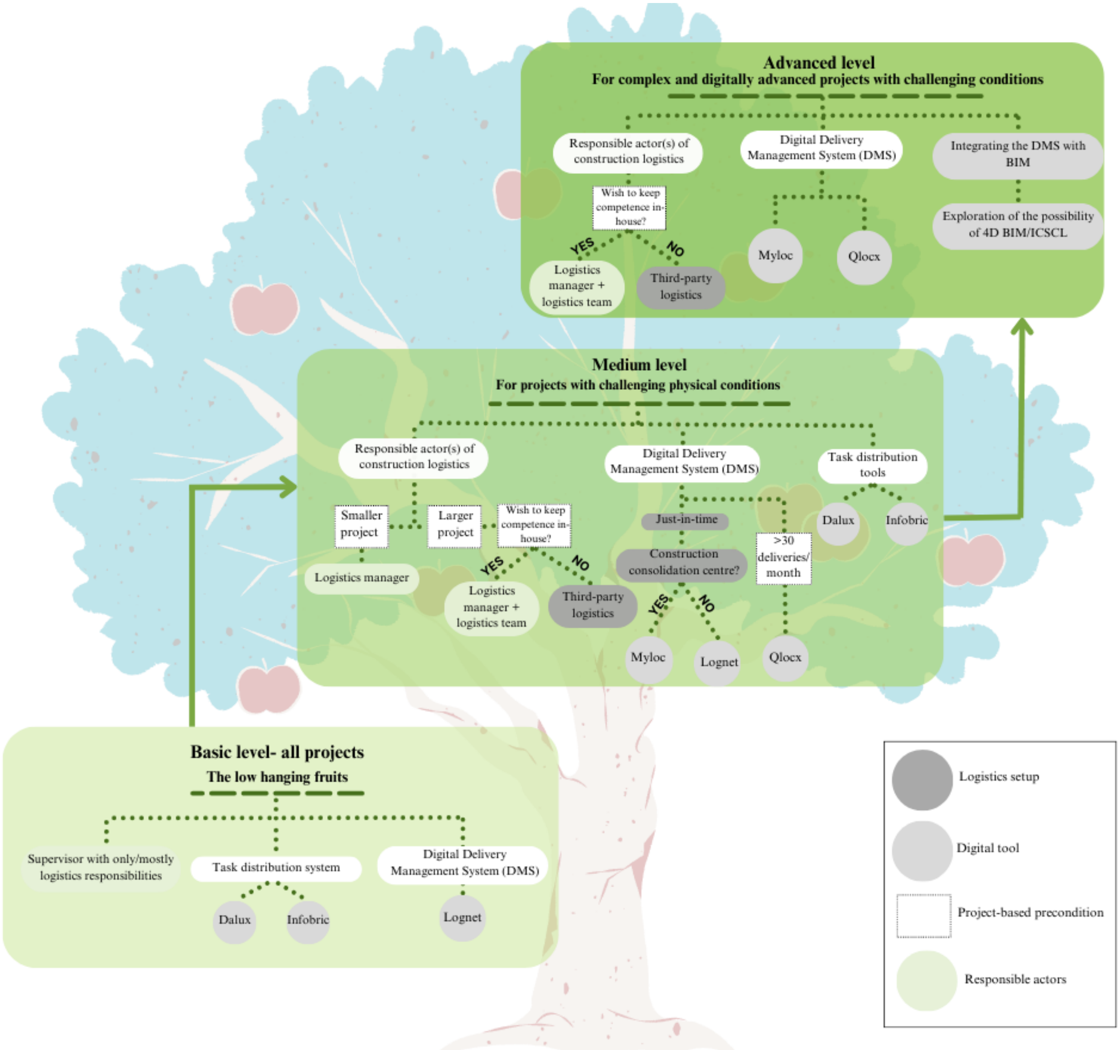

Figure 6.1: Planning guide for levels of digital and operational advancement in construction logistics

The *Basic level* includes the low-hanging fruits available for reaping in all projects regardless of preconditions, that were found to be most apparent in the DMS tools. Whether or not a project uses a digital tool for scheduling deliveries, the scheduling itself is essential for avoiding clashes and unforeseen events. The added control and comprehensibility found in the case projects that utilized digital DMSs is undoubtedly an important asset that was missing in the project that did not. Furthermore, all of BRA´s projects should at the very least utilize Infobric for inspection rounds, and Dalux for the creation of WAPs. Regarding which actor is responsible for the

CLM and CSCM onsite, the study has shown that it is much more beneficial to focus the responsibility of the logistics on one actor rather than distributing it to several.

The *Medium level* is appropriate when the physical attributes of the site are challenging- if the space available for unloading is small or sensitive to congestion, or when there is limited access to the site. These preconditions create a need for BRA to take consideration in the choice of DMS; Lognet is sufficient enough if the project chooses to only utilize just-in-time (JIT). In comparison to Myloc, Lognet is cheaper, while Myloc provides more complex functions that would be suitable when also utilizing a construction consolidation center (CCC). The medium level also includes using a digital delivery container to increase safety and save costs in larger projects. Furthermore, the actors responsible for the construction logistics should either be a logistics manager for smaller projects who in larger projects leads a logistics team or a third-party logistics (TPL) provider. It should be noted that the employment of a TPL provider inhibits the improvement of in-house logistics competence at BRA. However, this option may be favorable when an advanced logistics level is required, but the in-house competence among site management is not sufficient enough. If the number of deliveries exceeds 30 per month, Qlocx is beneficial to install as it will improve productivity and safety onsite.

The *Advanced level* should be pursued when all preconditions of a project contribute to complex construction logistics, including demands from clients and/or environmental certifications. It requires a certain level of digital proficiency in general by project management. On this level, Myloc is favored over Lognet because of its broader spectrum of functions. In addition, Qlocx should be used as it is assumed that projects of this complexity will gain from using a delivery container. The advanced level requires integrated construction supply chain logistics (ICSCL) between the DMS and building information modeling (BIM) tools, which in this study is represented by Dalux. Such integration can be further developed if BRA adopt 4D BIM in the future. Regarding task distribution, it has been found that the functions provided by Trello and Infobric are present in Dalux, which thereof should replace the other two as it is more efficient to utilize one system for several purposes.

6.5 Recommendations to BRA

BRA would benefit from a reorganization regarding construction logistics planning in order to achieve substantial advancement in its construction logistics management through earlier implementation. The level of operational advancement is dependent on the company's ability to evaluate what measures are needed and will contribute to productivity. Early involvement in terms of planning of logistics management, including choice of logistics set up is crucial for the implementation's success and so a standardized CLM to some degree would aid the company in achieving well-functioning logistics organizations. Since the preconditions of construction projects vary, the following logistics measures are recommended in order to suggest a standardized way of planning the logistics at the beginning of a project.

- Assign the responsibility of logistics to a specific person or team onsite in all projects, to avoid double handling and improve comprehension of activities. Depending on the project size this person can also hold other responsibilities (as for minor projects) or solely be devoted to logistics for larger projects. Larger projects may also require a dedicated team, as one person can not alone cope with all logistics issues

- Use a digital delivery management system in all projects of reasonable size to increase coordination between actors on site and suppliers and decrease the frequency of unplanned events

- Use delivery containers with digital locks for all projects that receive 30 or more deliveries of small goods per month, and projects where outdoor space is sensitive to traffic congestion

- Use task distribution systems for material handling and other non-core activities carried out by non-producing workers, as well as for inspection rounds

- Create standardized methods for evaluation of logistics tools and methods, using indicators that do not only cover cost and time savings but softer aspects such as safety and working environment as well

- Consider using Dalux as a comprehensive tool for task distribution and inspection in large or complex projects.

6.6 Suggestions for further research

The advancement of digitalization in logistics holds great potential for the industry and should be the focus of future research. To provide incentives for contractors, in-depth research is needed to quantify the potential tangible cost savings from using digital DMSs. In order to create lasting change in the industry, research should also explore new measurements and evaluation methods of digital tools for logistics from other perspectives than cost and time savings. Lastly, studies of the effects of an earlier involvement of CLM and CSCM on production efficiency could bring about useful conclusions to further improve the construction process.

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A

Appendix 1

Appendix 1 presents the interview guide on which the semi-structured interviews have been based. The guide has been modified when appropriate to fit the respondents' roles. The guide is presented in the original Swedish configuration below (Appendix A.1), followed by a version translated into English (Appendix A.2).

A.1 Intervjuguide

Inledande frågor

- Berätta lite om dig själv och vad du gjort innan detta projekt.
- Berätta lite om din roll i projektet/[alt. företaget]
  - Vilka är dina uppgifter/ansvarsområden projektet?
- Vad är det roligaste med att jobba som [din roll]?

Projektspecifika frågor

- Hur ser logistikorganisationen ut i ert projekt?
- Hur får du som [din roll] information om logistiken och vilken typ av information anser du vara viktig för dina beslut?
- I vilket skede kommer logistikplaneringen in i detta projekt?
  - Vad får ni med er från projekteringen?
  - Hanteras logistikfrågor redan i upphandlingsskedet?
- Hur involverade är kunden när det kommer till er logistik?
  - Vilka krav ställer de på er logistikorganisation?

- Hur skiljer sig [det projekt du är involverad i] från BRA:s övriga projekt när det kommer till logistik enligt dig?
- Hur håller man koll på vilka material som finns lagrade på bygget?
- Hur involverad är du i budget och prognos?
  - Hur fördelas logistikkostnaderna i budgeten?
  - Är det budgeterat för material- och leveranskostnader i detalj?
  - Har ni någon planerad buffert ifall material skadats, eller det sker förseningar?
- Hur upplever du att de digitala logistikverktygen fungerar?
- Vad är den allmänna uppfattningen av dessa program?
- Vilka digitala verktyg använder ni er av?
- Skulle du kunna rangordna dessa verktyg från de mest grundläggande och nödvändigaste till de mer avancerade och nischade?
- Är det rimlig inköpskostnad för verktygen?
- Vilka funktioner saknas? Om du kunde välja fritt oberoende på kostnad, vad hade du lagt till i projektet?

Generella frågor om logistik

- Kan du ge exempel på projekt som gått bra/dåligt logistikmässigt?
  - Vad gjorde ni annorlunda?
- Vilka är de vanligaste flaskhalsarna/stora utmaningarna man stöter på inom bygglogistiken?
  - Hur stor påverkan har dessa utmaningar på kostnader/tid/kvalitet?
  - Vad tror du är den främsta orsaken till att dessa utmaningar återkommer i projekt?
- Ranka dessa förutsättningar efter hur mycket de påverkar logistiken i ett projekt:

1. Byggnadens BTA
2. Projektsumma

3. Accessvägar till bygget
4. Tillgänglig avlastningsyta
5. Beställarkrav
6. Lagringskapacitet för material på byggplatsen

- Hur förhåller de sig till varandra?

A.2 Interview Guide

Introductory questions

- Tell us a little about yourself and what you have done before this project
- Tell us about your role in the project/[or company]
  - What are your tasks and responsibilities?
- What is the best thing about working as [your role]?

Project specific questions

- How are the construction logistics organized in your project?
- How do you as [your role] receive information about logistics, and what type of information do you consider important for your decisions?
- In what stage of this project is logistics planning introduced?
  - What information is given to production from the design phase?
  - Is logistics issues handled in the procurement phase?
- How involved is the client in terms of your logistics?
  - What requirements do they state regarding your logistics organization?
- How does [the project you are affiliated with] differ from BRA´s other projects in terms of logistics according to you?
- How does one keep track of which materials are stored onsite?
- How involved are you in budgeting and economic forecast?
  - How are logistics costs accounted for in the budget?
  - Are material and delivery costs detailed in the budget?
  - Do you have a buffer for material damage or delays?
- How do you perceive the functionality of digital logistics tools?
- What is the general perception of these tools?
- Which tools do you use?

- Can you rank these tools from the most basic and necessary to the most advanced and niche?
- Is the cost of the tools reasonable?
- What functions are missing? Given full freedom regardless of cost, what would you add?

General questions about logistics

- Can you provide examples of projects that went well/badly in terms of logistics?
  - What did you do differently?
- What are the most common bottlenecks/challenges one encounter in construction logistics?
  - How big is the impact of these challenges on cost/time/quality?
  - In your opinion, what is the biggest reason that these challenges keep reoccurring in projects?
- Rank these preconditions by their influence on logistics in a project:
  1. The building´s GTA
  2. Project cost
  3. Access to the building site
  4. Available area for unloading
  5. Client´s requirements
  6. Available stocking area
  - How do they relate to each other?

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