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Cross-project collaboration in the construction sector

A 4C CONTROL TOWER FOR CONSTRUCTION SUPPLY CHAINS

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van meijel

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Management summary

The Dutch construction industry is booming: it is the fastest growing sector in the Netherlands and there is a high need for new and renovated buildings and infrastructure. However, the growth of the Dutch construction sector is greatly inhibited by labor shortages, rising material prices and delays in the construction process. There are many inefficiencies in the construction process leading to significant failure costs and low profit margins. The bundling of resources and capacities has been found essential, especially in inner cities where space is limited and the livability of the city needs to be taken into account. There is a need to manage the logistics of multiple construction projects to make the construction process more efficient.

Previous research on this topic has proposed the use of the Construction Consolidation Center for last-mile delivery and the bundling of goods for multiple projects. In addition, an inter-organizational data platform, the 4C (Cross Chain Control Center) control tower, has been suggested to be crucial in the monitoring and planning of the various logistical flows. Although this control tower has only been described as a vision for construction logistics, the potential role and organization of this control tower for construction industry is not yet explored.

This study goes in-depth into the topic of 4C and attempts to understand what the implications are of a form of a 4C for the construction industry. An abstract design of a 4C is made using a business model framework to describe the business logic. This design is validated with industry experts to understand what value, information and processes the control tower could be supported and to assess its applicability.

The results point to many obstacles and uncertainties with regards to the development and use of the 4C control tower in the construction industry, including a lack of a clear governance model, a lack of a clear business case for the involved parties, improper chain-wide use of ICT, several (perceived) risks of data sharing, and a lack of data standardization.

Instead of a central actor orchestrating the supply chains, this study finds that an industry-wide protocol is needed that dictates the information exchange among the parties. The implications of this for the industry, as well as for VanMeijel Automatisering are discussed. As an IT provider, VanMeijel may benefit from the opportunities that arise when logistics data among parties is shared. This includes the addition of a new package to their software product, Metacom Online.

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1. Introduction

This chapter is the starting point of this thesis and provides an introduction to problem of the research domain. The first section provides some context and elaborates on the Dutch construction industry and the concept of Cross Chain Control Centers. This is followed by the problem statement of this research in section 1.3. Section 1.4 covers the research objective and questions. The chapter concludes with the research methodology in section 1.5.

1.1 Background

This section provides some context for this research. An introduction is made on the issues in the Dutch construction industry and the general concept of a Cross Chain Control Center.

1.1.1 Organizational background

This research is conducted in cooperation with Van Meijel Automatisering B.V. (hereinafter referred to as 'VanMeijel'). VanMeijel is an IT company that provides software and services for the construction sector as well as construction-related industrial sectors to support the digital transformation of the building process. VanMeijel was founded in 1987 and has grown to approximately 120 employees of which most are located at the headquarters in Emmeloord. VanMeijel is seeking out new opportunities to expand and improve their product and service offerings for its customers.

1.1.2 Dutch construction industry

The Dutch construction industry has been performing particularly well. Construction output has risen significantly for the fourth consecutive year. The sector saw a growth of 7.1% in 2018 and has a projected of 4.5% in the next two years (Rabobank, 2019). This growth is one of the highest of all sectors in the Dutch economy. This growth can be attributed to the public investments in new infrastructure. Also specialized construction companies and installers are expected to benefit greatly from this growth. Residential and non-residential building construction is expected to grow less rapidly than in previous years.

The construction sector can be divided into three branches:

Branch	English equivalent	Examples
Burgelijke & Utiliteitsbouw (B&U)	Building construction	Residential buildings; non-residential buildings (e.g. offices, schools); multifunctional buildings (e.g. shopping centers, sport halls, stadiums)
Grond-, Weg-, & Waterbouw (GWW)	Infrastructure construction (civil engineering)	Roads (e.g. motorways, cycle paths); hydraulic engineering (e.g. dams, canals); rail construction (e.g. railways, subways); earthworks (e.g. harbors, drainage
Gespecialiseerde/ industriebouw	Specialized Industrial construction	Oil and gas refineries, processing plants, power plants, manufacturing plants, equipment rental, waste processing, exceptional transport

Table 1 - Construction industry branches

There is need for new buildings and renovations to existing buildings to make them more sustainable. There is currently a residential building shortage in the Netherlands. In 2019, the shortage has built up to 300 thousand (Lissenberg, 2019). In the coming 5 years, 75.000 new buildings will need to be delivered each year, but in the past year only 69.109 permits have been issued (Rabobank, 2019). Before 2030, a million new residential buildings will need to be constructed (Vermeeren, 2018). Despite the need for building production, it is inhibited by labor shortages, rising material prices and delays in the building process (Rabobank, 2019).

1.1.3 Inefficiencies in the building process

The Dutch construction industry has been struggling with high failure costs (De Jong, Winkeler, & Van Meijel, 2018). Failure costs refer to all costs that are unnecessarily incurred in the production of the final product. They arise in every stage of the production process due to inefficiencies and the inability to meet the quality requirements of the client. Failure costs often translate into wastage of labor and materials, and inefficient utilization of space and production goods. The optimal use goods and labor is essential in an industry that has been struggling with severe labor shortages. In addition, construction companies have to operate in a highly competitive environment. Consequently, contractors have to settle for low profit margins as they have to cope with the pressure of delivering high quality product within time and budget.

Several studies have been conducted to capture the scale of the failure cost problem but estimating the exact costs has been difficult. Estimates of failure costs in construction vary from 8 to 15% (De Jong e.a., 2018). In 2001, failure costs were estimated to encompass approximately

7% of total revenue. This increased over the years to 10% in 2005 and 11% in 2009 (Busker, 2010). The inability to control the cause of the failure costs has led to this rise. Assuming failure costs constitute 11% of the total production revenue, the waste of revenue would amount to a total of €7.59 billion in 2019.

Failure costs are a persistent and almost accepted inefficiency in the construction sector. Opinions differ as to what the causes are of failure costs in the construction sector. The causes can be attributed to a multitude of factors and differ per company and project. A study conducted by USP and Bouwkennis (Bouwkennis, 2013) reveals that a substantial part of the inefficiencies can be attributed to insufficient communication and information exchange among project partners. Most of the costs arise two distinct phases of a construction projects: the preparation phase and execution phase. Failure costs in the execution phase of the project are estimated to be 43% of total failure costs. The cause of these costs during this phase can be attributed for 26% to the poor information exchange and communication. Figure 1 illustrates where problems may arise throughout the construction process.

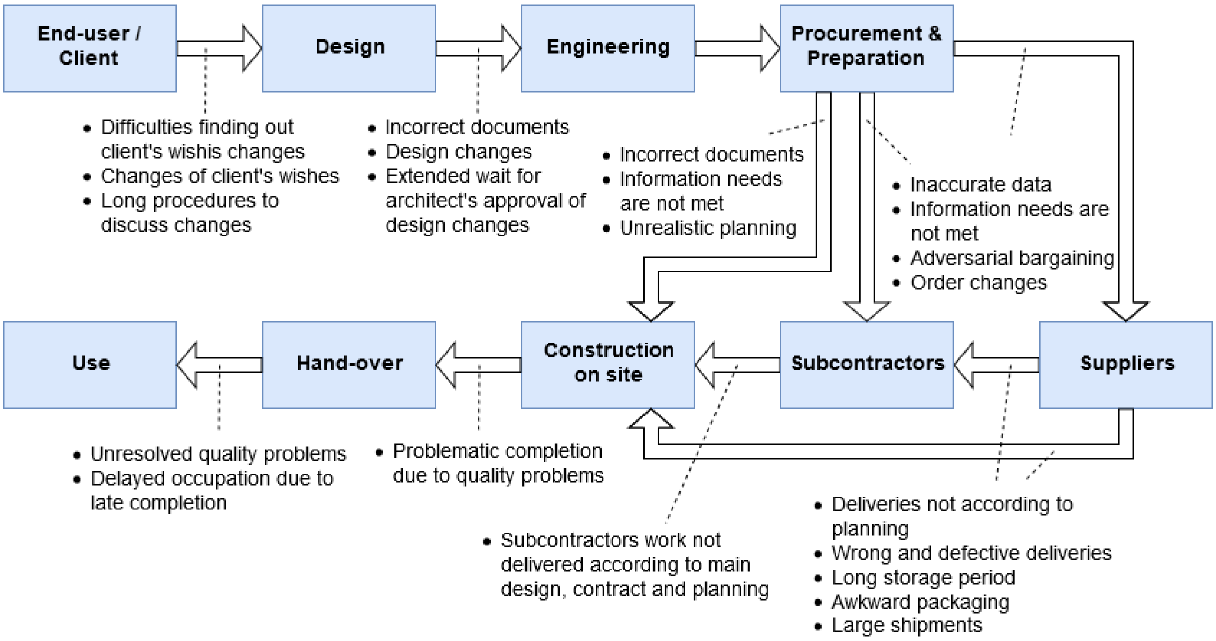

Figure 1 - Construction supply chain problems, based on Vrijhoef & Koskela (2000)

A distinction can be made in the moment failure costs are caused and the moment they manifest. A study conducted by USP and Bouwkennis (Bouwkennis, 2013) reveals failure costs mostly manifest during the realization phase and to a much lesser extent during the preparation phase and delivery of a building project. Although failure costs are almost never expressed in the initiation phase and design phase, contractors argue that the causes of failure costs can be attributed to these initial phases due to errors and changes in the design. An overall trend can be found that suggests that the vast majority of errors manifest in the execution phase, while the causes mostly lie in the design phase. The highly phased process of construction makes the realization phase of the project more prone to errors.

Noordhuis (2015) conducted an extensive analysis of the failure cost problems and found three distinctive fundamental causes:

- Fragmented building process
  The building process is divided into separate functional tasks which are often realized by different actors. Building process fragmentation refers to the strict separation and hierarchical organization of activities and has been widely described to be a major contributing cause to the industry's problems. The separation of activities and inter-dependencies of disciplines cause problems to build up as the construction progresses.
- Low degree of standardization
  The low degree of standardization has been found to increase complexity and lower the learning effects. It is estimated that standardized building parts make up 10 to 20% of all parts in the residential building branch and less than 5% of parts in the non-residential building branch (Noordhuis, 2015). For an efficient building process, there is a need for standardization on the process level and on the product level by standardizing building components.
- Lower price tendering
  Competition between contractors is fierce resulting in prices being determined on the basis of a product's minimum requirements. Tendering at the lowest price certainly discourages the search for solutions that provide the best price/performance for the client. As a result, a low price can ultimately result in higher (operating) costs and lower quality.

1.1.5 The need for Supply Chain Management

The concept of supply chain management in construction has gained ground in recent years. By applying effective management of the current construction supply chains, construction companies attempt to increase productivity and reduce failure costs of building projects. Supply chain management (SCM) is a philosophy that describes how organizations can gain strategic advantages through effective management of their supply chains (Saad, Jones, & James, 2002). It is the means through which improvements in flow of goods, finance, and information and reductions in costs can be achieved. In the manufacturing industry, the application of SCM has been proven to be successful in creating significant benefits throughout the supply chain. The benefits include cost reduction, value creation and increased competitiveness (Christopher, 2016).

In a construction project, supply chain management involves the management of activities undertaken by involved construction project from design to completion. Depending on the scope of the project, the supply chain can consist of large range of participants, including the general contractor (GC), building material suppliers, logistics providers, architects, constructors and installers, and the client or developer.

As of yet, the application of supply chain management in construction has met many difficulties. The peculiarities of construction, including unique building products, temporary supply chain configurations, and site-specific production, prevent SCM to be applied as efficient as in manufacturing (O'Brien, Formoso, Ruben, & London, 2008; Vrijhoef & Koskela, 2000).

Vrijhoef (2011) describes two ways of dealing with advances in building construction. First, the elimination of the aforementioned peculiarities by means of standardization and prefabrication. It is argued that simplifying site construction techniques originating from manufacturing can be applied in construction through the industrialization of the building method. However, the applicability and impact of these innovations may vary greatly depending on the size and complexity of the building projects. Overall, there has been little positive response to performance improvement efforts in construction, largely due to the finite duration of the projects and the project-by-project mindset of the involved companies (Tommelein, Walsh, & Hershauer, 2003).

A second approach for dealing with the unstable building production is to develop or adopt techniques that manage to deal with the uncertainties and changes of construction (Vrijhoef, 2011). There is much room for improvement in the area of inter-organizational information exchange. According to Lönngren et al. (2010), there are various IT systems available to construction companies to manage their business, but most are unable to aid in the information flow and the provision of visibility across organizations. The systems used involve ERP/MRP systems that serve to automate and provide visibility of single business unit functions, rather than (O'Brien et al., 2008). As SCM has only begun gaining ground in construction, the necessary IT tools are needed to support the supply chain improvement practices.

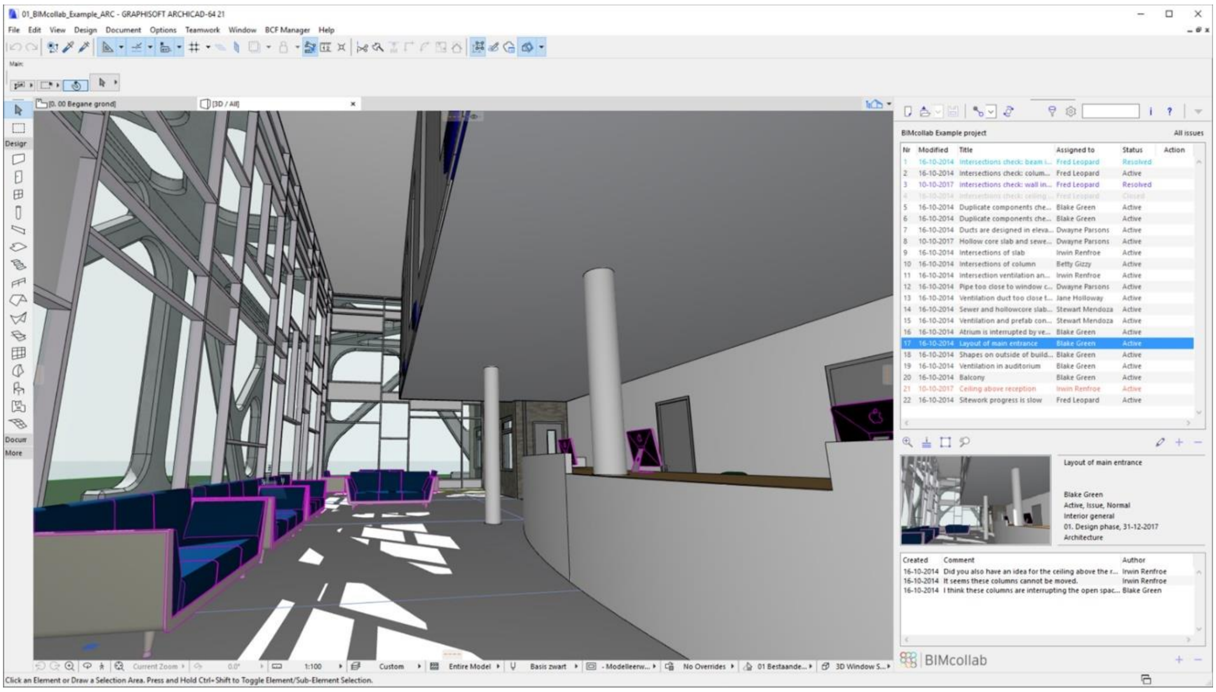

Figure 2 - BIM example in Revitt, copied from BIMcollab

In recent years, new logistical concepts and advances in ICT, such as the Building Information Model (BIM) and sensor technology, have made their way into the construction industry. FigureFigure 2 shows an example of a BIM project in the Revitt application. BIM is mainly used to communicate the design of a construction products, including its components, among the client, architects, the general contractor with its subcontractors. However, it is not used for the logistics process during the realization phase.

The logistics of a project involves a large number of suppliers that deliver goods to the construction site. There is need for better communication in the logistical process throughout the supply chain to properly coordinate the supply of goods to the construction site. is especially needed in inner cities, where the logistics of a project are confronted with congestion, limited space on-site, and regulations with regards to accessibility and emissions.

Several construction companies have turned to a Construction Consolidation Centers (CCC), a logistics hub that allows for last-mile delivery of goods to multiple construction sites. This logistics center is used in an attempt to make the flow of goods from the suppliers to the construction site more efficient. The CCC has already proven to have significant benefits, but its use is still in its infancy.

1.1.6 Cross Chain Control Centers

Another concept that is proposed alongside the Construction Consolidation Center is the Cross Chain Control Center (4C). This concept is a relatively new in supply chain management and has been gaining attention among researchers and practitioners in several industries, including floriculture, chemical industry, e-commerce, and healthcare (De Weerd, 2018). It has been described as a control center from which multiple supply chains can be coordinated using state-of-the art technology and supply chain management concepts (Topsector Logistiek, 2015). As a central actor for multiple supply chains, the 4C is able to support chain-wide activities, such as forecasting, financial engineering, and data management, and create economies of scale. The 4C can also be used for transportation (e.g., by combining goods for transport between shippers) and warehousing activities (e.g., merging warehouse capabilities) to achieve new efficiency gains.

The concept of Cross Chain Collaboration Centers (4C) has been described as the next revolutionary step in supply chain management (Topsector Logistiek, 2015). The potential benefits of 4C services such as collaborative planning and resource bundling have been demonstrated (De Kok, van Dalen, & van Hillegersberg, 2015). Thus far, literature on the 4C concept has remained limited to the Fast Moving Consumer Goods (FMCG) supply chain to support the supply chain activities of shippers, logistics service providers, and retailers.

There is a clear need in construction to effectively support and facilitate supply chain management activities. As of yet, the creation and use of a 4C to support future collaborations has not gone far beyond academic explorations and has only been described as a vision for construction logistics. For construction, the 4C has been described a central control tower that monitors, plans and coordinates logistics activities of one or multiple building projects by integrating the relevant information systems and data sources. Questions remain regarding the role and functions of a 4C for construction logistics. Furthermore, the implications of a 4C for the involved stakeholders are not yet understood.

1.2 Previous work

Topsector Logistiek and the NTO conducted an exploratory study on the possibilities of a 4C Control Tower for construction logistics (De Bes e.a., 2018). This 4C project involves a consortium of a few large Dutch construction companies, trade associations, and knowledge institutions. In this project, multiple construction logistics concepts, including the Construction Consolidation Center (CCC, sometimes also referred to as a "logistics hub") and a 4C control tower, were analyzed.

The report stresses the need for better ICT to support new smart logistics concepts. There is both a need and a willingness to use smart construction logistics concepts by the large contractors due to the lack of insight and control in the logistics process. However, there are a number of challenges that prevent the adoption of these concepts. The studies conducted on site revealed that little measurements done during the construction process. This has made it difficult to provide insight into the effects of new concepts for improvement. Insight into the costs and benefits is mostly theoretical, which makes the adoption of construction logistics solutions difficult (De Bes e.a., 2018).

The study "4C in de bouwlogistiek" (Ludema & Van Merriënboer, 2016) found a lack of appropriate ICT supporting the information exchange for the construction logistics process. They claim a need for tactical and operational planning of the construction process. BIM does not allow for a continuous dynamic planning for construction logistics that is linked with the partners of the construction project. The report concludes that there are currently no examples known of dynamic digital planning systems with a direct link between BIM and building planning (4D BIM).

It is argued that a 4C control tower is needed to support the logistics processes across the construction supply chains. This control tower would have to link the logistics processes with the tactical and operational planning of the construction process. This vision of a control tower came about after consultation with stakeholders involved in construction logistics. However, a lot of questions remained unanswered. The study did not go in-depth of the inner workings and wider implications of a 4C model in construction logistics, including the organization, governance and ICT requirements. The 4C control tower is mainly an abstract vision for future construction logistics and is left to industry practitioners to further design and implement.

1.3 Problem statement

This thesis describes the ways in which the 4C can support the supply chain management activities of the parties involved for multiple construction projects. This 4C is aimed to improve the efficiency of the logistical flows across the supply chains and to thereby minimize the failure costs of construction projects. This thesis takes two perspectives when describing the design and implications of the 4C: a business and a technical perspective. One way of describing how a business creates and captures value are business models. The business functions of the 4C are written from a managerial perspective to allow business managers to better understand and appraise the business. This may help them in the formulation of a business strategy that will allow a 4C to be implemented in the future. Similarly, the IT requirements may provide VanMeijel Automatisering, as an IT provider, with insight into the implications of a 4C with regard to their current product portfolio and helps them anticipate on new business opportunities. To summarize, the goal of the thesis is twofold:

- To design and validate a blueprint of a 4C for construction using a business model framework; and
- To identify the requirements of the inter-organizational IS infrastructure that allows the relevant stakeholders to participate in the designed 4C.

1.4 Research questions

The problem statement and the goal of this study is used to formulate the main research question.

What would a 4C look like that supports and facilitates supply chain management activities of multiple construction projects?

The main research question is divided into several successive sub-questions:

RQ1. What is construction supply chain management?
RQ2. What are 4C control towers and how are they applied in logistics?

The answers to these two questions are provided in the literature review section. They provide an understanding of how construction supply chains work and how 4C control towers are applied in logistics.

RQ3. What would a business model of a 4C control tower look like?
RQ4. To what extent does the designed 4C control tower fulfil the needs of the stakeholders?

In order for the business model to be viable, it will need to deliver value to the involved stakeholders. The developed business model is validated by stakeholders and experts on the likelihood of adoption and is adjusted where necessary.

RQ5. What are the IT implications of the designed 4C control tower in general, and for VanMeijel in particular?

The validated business model is combined with the findings from literature to come to recommendations to VanMeijel Automatisering on how to address the development of a 4C with regard to their current product portfolio.

1.5 Research Methodology

1.5.1 Research approach

The main research method used for this study is Design Science Research (DSR) as it has proven to be a useful method for information systems development (Hevner, March, Park, & Ram, 2004) DSR is a method that helps structuring the thesis and guide the formulation of the research question. The goal of the research is to develop a solution to a complex problem needed in achieving in the development, use and assessment of information systems within an organization. The utility of the artefact is the main goal in this research.

Hevner et. al (2004) characterizes the problems in design science as follows:

- Unstable requirements and constraints based on ill-defined environmental contexts
- Complex interactions among subcomponents of the problem
- Inherent flexibility to change design processes as well as design artefacts (i.e., mallable processes and artefacts)
- A critical dependence upon human cognitive abilities (e.g., creativity) to produce effective solutions
- A critical dependence upon human social abilities (e.g., teamwork) to produce effective solutions

Looking at the specifications for wicked problems, DSR seems like a perfect fit for the problem at hand. This approach involves both practical and knowledge problems (Wieringa, 2010), as illustrated in Figure 3. The organizational context determines the goals of the practical problems and is subject to change due to the implementation of an artefact. The knowledge base is used to answer knowledge questions and can be extended when the new knowledge is gained through investigation.

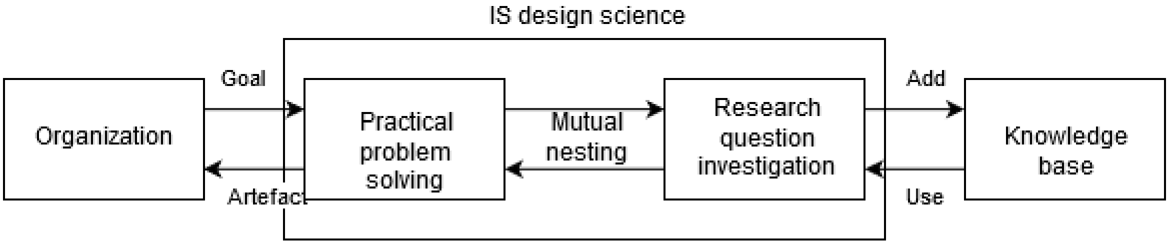

Figure 3 - Practical knowledge problem (Wieringa, 2010)

Wieringa (2010) describes a design cycle to tackle design problems. This study applies this design cycle to structure the research approach. The cycle consists of: (1) design problem (2) treatment design, (3) treatment validation, and (4) implementation & validation. The research approach of this study is made based on this cycle (Figure 4).

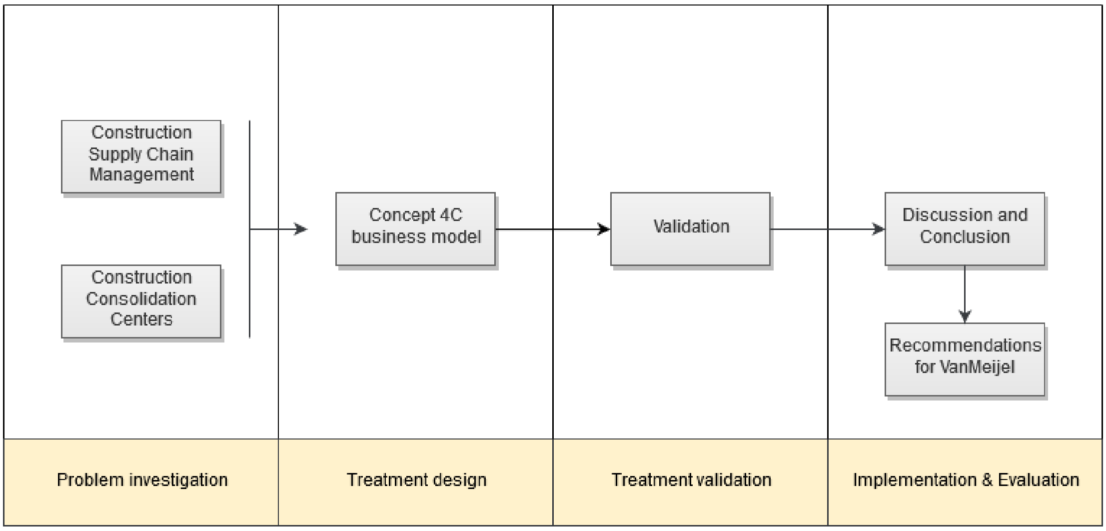

Figure 4 - Research approach

1.5.2 Literature review

The problem investigation and treatment design is primarily done through literature review. Literature was selected from a broad range of sources. In addition to scholarly papers, publications of consultancy firms and research institutes where used in this research. The relevant literature is identified from the available scholarly databases. A comprehensive search is carried out to find as many relevant literature as possible. This result of this search is a set of papers that can be used for this study. The search strategy involves a number of databases and key words that were determined to be relevant. The chosen journal databases include Scopus, Sciencedirect, Web of Science and IEEE. With help of a search operation, a list of papers where presented on these databases. The title and abstract where used to determine the relevancy of the papers.

1.5.2 Expert interviews

This study started with an investigation into the problem statement and subsequent formulation of the research questions. To support the exploration the research domain, several interviews are conducted with experts both in the field of 4C and the construction industry. These interviews were unstructured in nature and provided a range of perspectives on the topic which is desirable during the early stage of this research.

In the second phase of this research, several semi-structured interviews are conducted with experts in the construction industry and the field of 4C. The semi-structured character of these interviews allow for any deviations in case new significant findings emerge during the interviews that need further investigation (Bryman, 2012). The explorative nature of this study calls for a more flexible approach to how the interviews are conducted.

The aim of the expert interviews in this phase is two-folded. First of all, the interviews with experts will result in valuable input regarding the creation of the of the research artifact. After the design, the same experts are interviewed to validate the solution. The second aim of these interviews is revealing the perception of the experts towards supply chain integration and 4C. The interviews are transcribed and coded to allow for further analysis of the data. Together with the findings of the literature study, these results are used to answer the research questions.

1.5.3 Business model design

The 4C for construction is designed through the method of business modeling, the process of designing business models. "A business model describes how a business creates, delivers and captures value" (Osterwalder, Pigneur, & Tucci, 2010). It demonstrates the structure of revenues and costs associated with the operations of the business (Teece, 2010). A design of a business model allows decision-makers to easily communicate and assess the inner workings of a business (Morris, Schindehutte, & Allen, 2005; Zott & Amit, 2010).

The business model concept is used to better understand and contemplate about the possibilities of the 4C functions. This study uses the Business Model Canvas (BMC) to understand the business logic of the 4C. The BMC has proven to be a successful framework as it has been used in many businesses to rethink old businesses and explore new business opportunities (Osterwalder e.a., 2010). The BMC was proposed as a strategic management tool: "The BMC is like a blueprint for a strategy to be implemented through organizational structures, processes and systems" (Osterwalder e.a., 2010).

The BMC can be divided into four main areas:

- Product: to describe the products and services that the firm offers.
- Customer interface: to describe the delivery of the product and the relationships with the customers.
- Infrastructure management: to describe the infrastructure and logistical aspects of the business.
- Financial aspects: to describe sustainability of the business through its revenue model and cost structure.

The four areas are divided into nine building blocks, including value proposition, customer relationships, channels, customers segments, key partners, key activities, key resources, revenue model and cost structure.

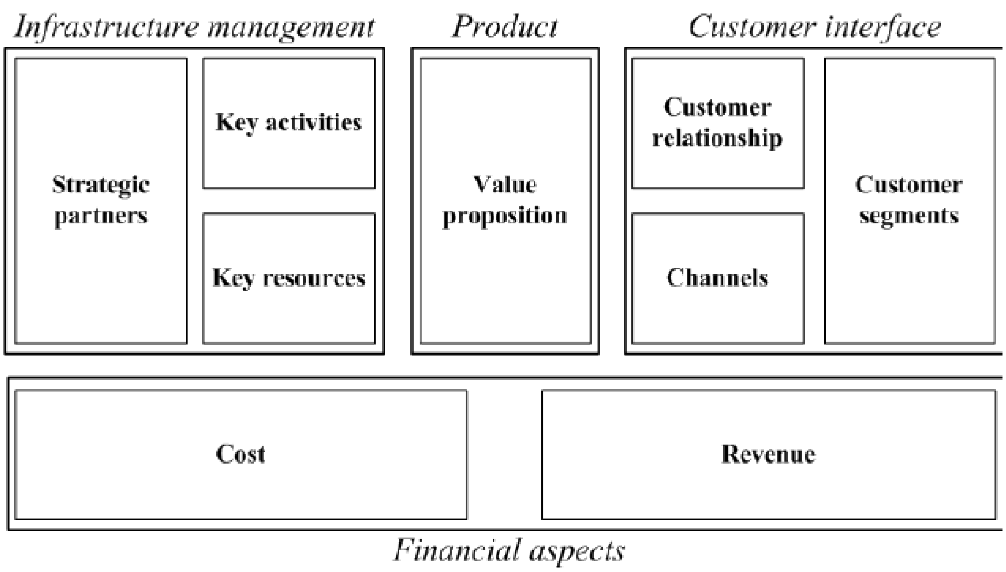

Figure 5 - The Osterwalder Business Model Canvas, copied from Kleef, Noltes, & Van der Spoel (2010)

Thus far, the use of any business modeling technique for the 4C concept has been limited. There is a need for new business models in this regard (Topsector Logistiek, 2015). In order to complete the building blocks for the 4C, current business models for control towers and intermediary logistics service providers have been analyzed. A review of the academic and professional publications on this topic was conducted and combined with the current literature on construction to get a general overview. Based on the business models described in literature, the application of them for construction was investigated.

2. Literature review

2.1 Construction supply chain management

2.1.1 Supply chain management

Many authors have tried to capture the essence and meaning of the supply chain concept in words. Christopher defines a supply chain as: "a network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate consumer" (Christopher, 2016).

A supply chain refers to the flow of information and goods up and downstream. In its broadest sense, a supply chain consists of a network of suppliers and customers that are involved in the production, from the raw material to the distribution of the final product to the user. Figure 6 represents a simplified overview of the flow of materials and information across a linear supply chain.

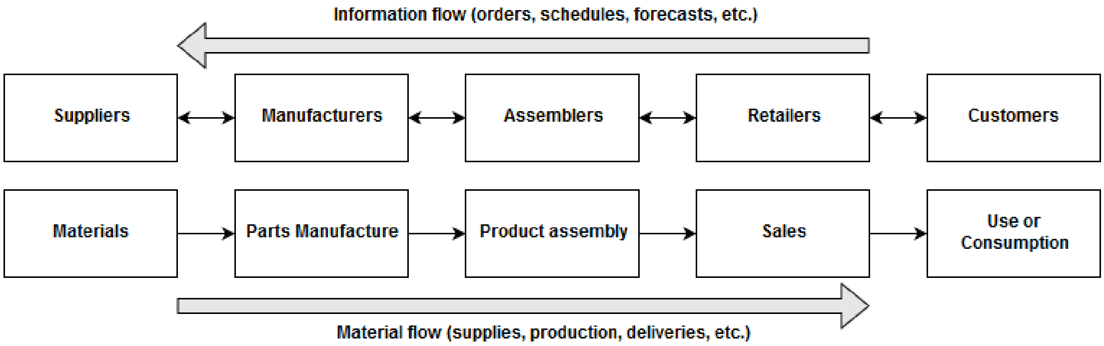

Figure 6 - Linear supply chain

The concept of Supply chain management (SCM) can be traced back to the automotive industry. The Toyota car factory was among the first to implement SCM where it was used to deliver their product on a Just-in-Time (JIT) basis (Shingo, 1988). The goal of supply chain management in this system was to reduce stocks and encourage better quality control. It regulated the right amount of supplies to the Toyota motor factory in a timely manner.

Supply chain management can be defined as: "the systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole" (Mentzer e.a., 2001).

The concept of SCM evolved as a distinct subject of research and attained an autonomous status in industrial management theory (Bechtel & Jayaram, 1997). With the increase in understanding of supply chains came new approaches and concepts, such as the value chain, that further influenced the concept of SCM. Although the contemporary concept of SCM is largely dominated by logistics, it is used to encompasses more than just logistics (Van der Veen & Robben, 1997).

2.1.2 Construction characteristics

The construction industry has been criticized by its low productivity and the slow rate of performance improvement (Woudhuysen & Abley, 2004). Various studies point to the inherent characteristics of the industry (Barbosa e.a., 2017; Changali, Mohammad, & van Nieuwland, 2015; Loera, Espinosa, Enríquez, & Rodriguez, 2013). The construction industry has certain peculiarities that distinguishes it from other project-based industries and make the production of a building product a relatively complex and unstable undertaking(O'Brien e.a., 2008; Vrijhoef & Koskela, 2005a). Vrijhoef and Koskela (2005b) categorize the peculiarities of construction into three levels: product level, production level, and the industry as a whole (see Figure 2) These levels are described below:

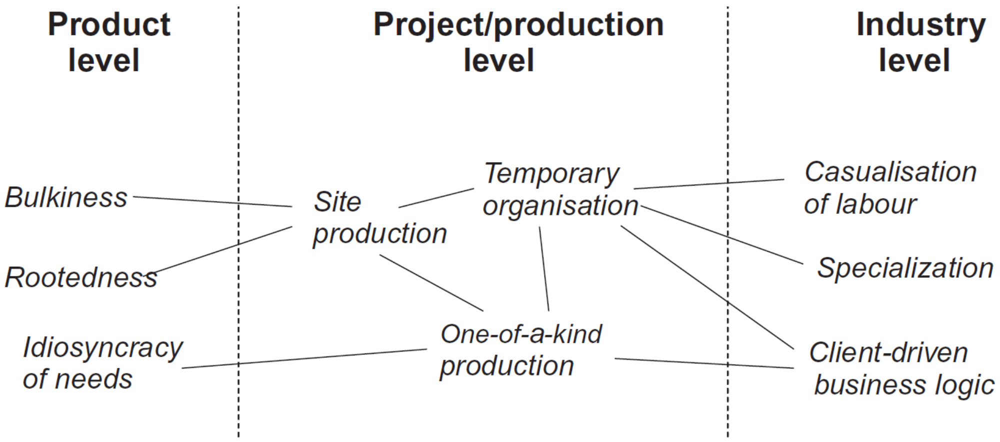

Figure 7 - Characteristics of the construction industry (Vrijhoef & Koskela, 2005b)

- <u>Product level</u>

  There are several specific features of the construction product that greatly affect the production level, including product lifecycle, immobility and impact on surroundings. The products are typically unique due to the idiosyncratic needs of the client and the socio-economic context it is constructed in. For example, construction products can be located in a densely populated area which may affect the way the product has to be produced. The features of the immobility, heaviness and bulkiness has also been ascribed to the construction items (Ofori, 1990). In general, construction products are rooted to a specific location which means that the assembling is done on-site.

- Production level

  The production is dependent and bound to the aforementioned characteristics of the building product. This means that the production is strongly aimed towards a particular site to deliver a customized unique product to a single client. The one-off approach has been described as the "prototype nature" of construction industry (Koskela, 2000). The construction industry is not unique in the characteristics of its production organization since they can be found in other industries as well, such as offshore and mining. However, the building situation is unique due to the specific combination of these characteristics (Vrijhoef, 2011). By addressing the combined characteristics and the independent relationship, concept from other industries could be applied. The adaption and translation of those concepts into the construction context may help the industry overcome the problems in production.

- Industry level

  The construction industry itself is characterized by high levels of fragmentation involving many Small and Medium-sized Enterprises (SMEs) of different specializations. Larger construction firms often take the role as general contractor to coordinate the building process. Due the wide variety of trades and the casualization of labor, construction projects have been regarded as the "epitome of a loosely coupled system" (Dubois & Gadde, 2002). The different firms work on different construction project in constantly changing coalitions. The interaction between the different parties is relatively informal compared to process-driven industries. The industry is a typical demand driven industry where the product is seldom predefined and the client initiates the construction.

2.1.2 Construction supply chains

The construction supply chain (CSC) refers to all parties that exchange goods, information, and finance related for the completion of a particular construction product (Xue Xiaolong, Shen Qiping, & Ren Zhaomin, 2010). The flow of goods originates from the raw material producer and ends at the client. In the opposite direction, there is a flow of funds as a function of risk taken by each stakeholder and the added-value of their services. The flow of information is bidirectional between all stakeholders involved with the project.

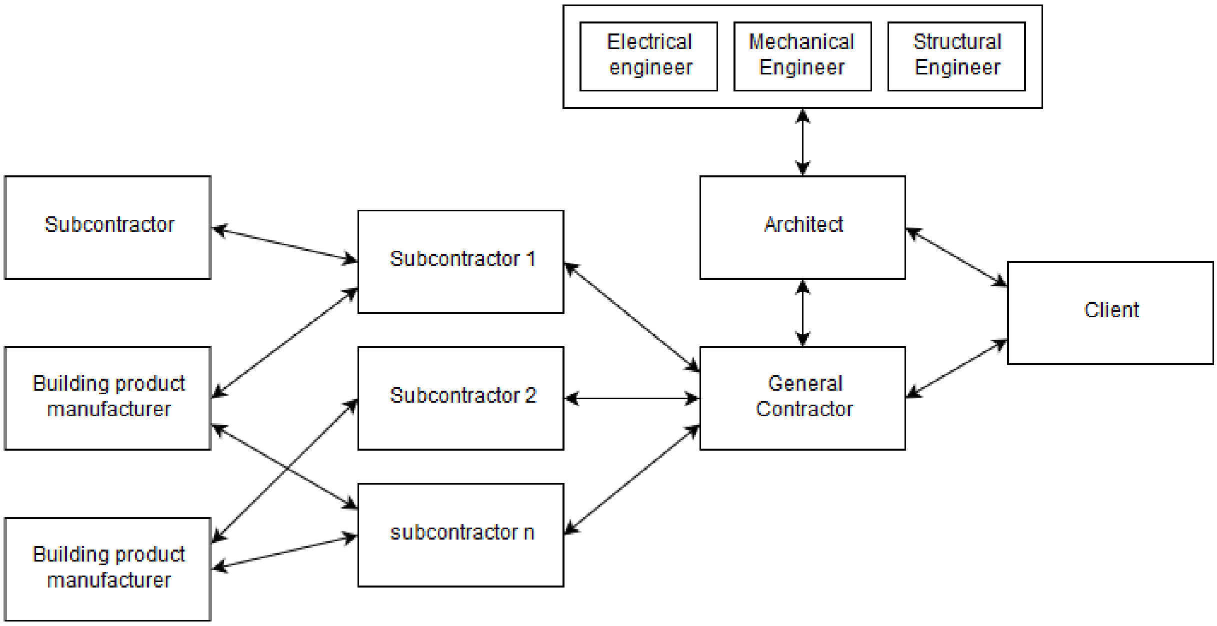

Figure 8 - Simplified illustration of a construction supply chain, own illustration

The CSC can be a network of a range of different parties, including a client/owner, designer/architect, general contractor (GC), subcontractors, and suppliers (Xue, Wang, Shen, & Yu, 2007). Figure 8 illustrates a simplified model of the value exchange in a typical CSC of a construction project from the viewpoint of the GC. It is not uncommon for contractors to outsource certain work. Ultimately, a project could have multiple tiers of subcontractors and suppliers that deliver certain goods or services.

Supply chain stakeholders

The outcome of a project can be attributed the joint effort of all actors by contributing in the design, construction, finance, consulting and other operation services (Narbaev & De Marco, 2011). Although some of these parties such as designers and engineers, can also be involved in a manufacturing supply chains, they play a large role in the construction process due to unique characteristics of the construction project (O'Brien e.a., 2008). The supply side of the supply chain consists of the contractor and the suppliers, the demand side consists of the contractor and the client. and the suppliers (Papadonikolaki, Verbraeck, & Wamelink, 2017). There are nine types of stakeholders involved throughout the building lifecycle (Geraedts & Wamelink, 2010). These are described briefly below:

<u>Client</u>

A client of a construction project can have different degrees of expertise and experience with the building process. The non-professional client has limited to no experience and requires the assistance of experts throughout the building process. The professional clients have acquired their own expertise due to their frequent experience with the building process. Clients include landowners, future owners, project developers, executive contractors, investors, government, and housing corporations. The varying level of expertise involvement of the client types greatly influences the construction process.

Architects

Architects, like the clients, have a major influence on the building process. Traditionally, the architect advised the client from initiation phase up to the completion of a building. The architect is also the expert in the field of translating the needs of the client to a design by using both an engineering and design approach.

Engineering consultants

Engineering consultants can be involved in various ways throughout the construction project. They can have contractual relationships between a consultant, client, contractor, and building manager, with each type of relationship affecting the building process in a different way. The advisor can be selected by the architect or construction manager or have an existing relationship with the client.

Construction management firms

Construction management firms have a wide range of tasks to the construction supply chain in both its demand and its supply. They advise client in the specification of requirements and the supervision of construction processes, and they support contractors in the coordination of complex processes involving investors, users, advisers, and executing parties.

Contractors

There are many ways a contractor can be involved in the construction process depending on the construction phase (early or late in the process), its role, (ranging from advisory in construction teams to only the core business of construction on site after a successful tender procedure), and the organizational and contractual context of the project. The contractor is responsible for the construction of the product. There are three types of executive contractors: small contractors for small-scale projects, and renovation or maintenance; medium-sized companies that either merge into larger conglomerates or specialize in specific market segments; and large construction companies operating on an international scale and delivering complete construction products from initiation to maintenance.

- Secondary contractor: a secondary contractor is a contractor that operates in addition to the main contractor on a project. This contractor operates on a separate contract with the client. For example, two contractors may work on two separate building in one complex simultaneously. In this situation, the coordination between the contractor parties is critical.
- Subcontractor: a subcontractor is hired by the contractor and does not have a direct contract with the client. Examples are: installers, road workers, plasterers, plumbers, etc.). The trend for many large contractors is to employ less staff and allocate more work to subcontractors.

Manufacturers and suppliers

The manufacturers and suppliers provide the materials for the construction of the building. The materials vary from raw materials to prefabricated building components. Certain suppliers that deliver project-specific materials (e.g. prefab concrete) are often involved early in the construction process due to their considerable lead times.

Real estate agents

Next to their role as a mediating party between buyers and sellers of houses and offices, real estate agents are among the first parties clients contact for starting a construction project. The agent is therefore an important partner for a construction management firm as a source of information for acquisition.

Tenants or users

The tenant or user is the stakeholder who will move into the constructed building. The user is in many cases an anonymous party, but can also be the client. If the user is involved early in the construction process, they can be involved in the decision-making and influence the design of the building.

Government

Next to the role as a client, the government can also take the role of service provider, policy-maker, and supervisor, on local, regional, and national level . The main task of government is the protection of public interest, overseeing the construction, and adjusting the building policy accordingly.

Characteristics of construction supply chains

Due the unique peculiarities of the construction industry, the construction supply chain (CSC) typically has the following characteristics:

Fragmentation and complex

CSCs can be very complex, especially in large construction projects (O'Brien e.a., 2008). This complexity can be attributed to need for a variety of materials and specialized parties at the construction site, including equipment suppliers and subcontractors. The industry has wide variety of disciplines, such as developers, builders, engineers and architects, with relatively high share of Small to Medium-sized Enterpises (SMEs). Complexity increases as more people get involved in a project with the involvement of multi-tier suppliers and subcontractors. Larger construction projects may involve hundreds or thousands of suppliers and subcontractors which requires a great deal of organizing, planning and collaboration between supply chain parties (Taylor & Bjornsson, 1999).

Converging

CSCs are converging supply chains where all materials are directed to a particular construction site to be assembled into the final project (Vrijhoef & Koskela, 2000). Unlike manufacturing supply chains where many products can be assembled in different places and distributed to customers, CSCs are set around a single product designated for a single client.

Make-to-order

The traditional CSC has been typified as a make-to-order (Ballard, 2005; Gosling, Purvis, & Naim, 2010; Vrijhoef & Koskela, 2000; Winch, 2003). Figure 9 illustrates the different decoupling points throughout the supply chain. The construction supply chain is very rarely set up for 'modified purchase' (assemble-to-order) and almost never for 'routine purchase' (make-to-stock) (Noordhuis, 2015). In a make-to-order production system, production is driven by the demand of the clients. Firms work in constantly changing coalitions on construction projects due to the unique characteristics of the product. Issues in project management and production can often be attributed to the disconnect between design and production. Moreover, many small and specialized firms are involved in the construction of the unique products. The interdependence of the parties within the chain contribute to the persistence of problems originating upstream and even to the increase of problems downstream (O'Brien e.a., 2008).

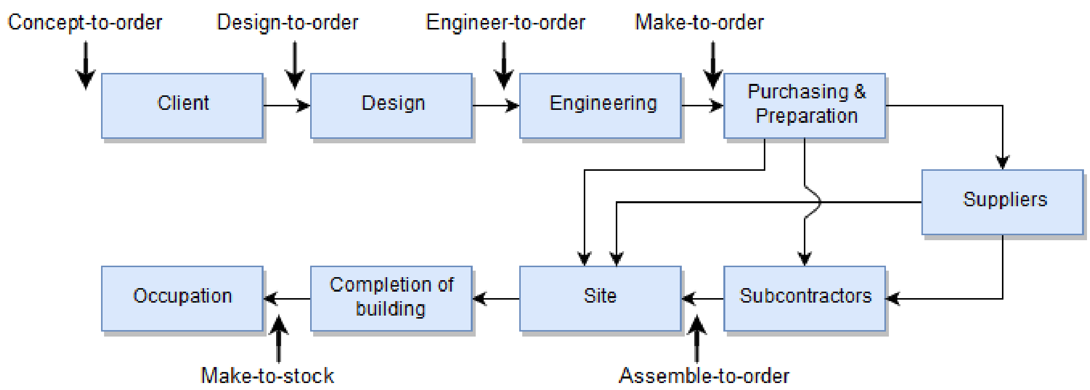

Figure 9 - Decoupling points throughout the supply chain

The construction industry is a project-driven industry where often one-off buildings are constructed. Standardization is particularly low in comparison to many production industries. The production of a construction product is done at temporary sites by actors that are only temporarily involved with the construction project. The short-term focus incentivizes supply chain parties to try and leverage every opportunity they get within the boundaries of an existing contract (Aloini e.a., 2012; Vrijhoef & Koskela, 2000).

2.1.3 The building life cycle

Literature shows several categorizations of project phases depending on different points of view (Antunes & Gonzalez, 2015). There generally is not one process for a construction project due to their unique characteristics. While the project phases are typically completed sequentially, there are project situations where they can overlap. The process heavily depends on the parties involved, the type of product, the contractual relationship among parties, and many other factors. Geraedts and Wamelink (2010) distinguishes between four phases that can be found in a typical construction project: initiation, preparation, execution, and commissioning.

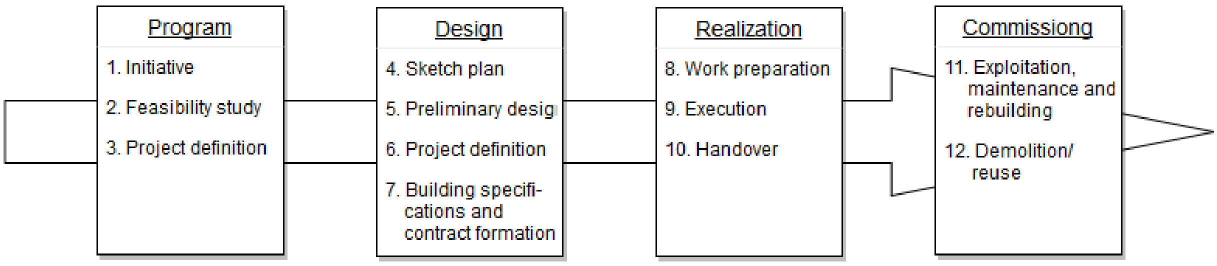

Figure 10 - Building life cycle

Program/Initiation

A project starts with a client defining the needs and conditions of the end result. In construction, this is called “the demand”(Ashworth, 2012). Two types of demand can be identified in construction: functional and technically specified demand (Vrijhoef e.a., 2013). In functional demand, the client, e.g. the owner or initiator of a project, describes a certain problem and specifies the functional requirements of a project. This is followed by an interactive meeting between contractor companies and the client in which the contractors present their ideas on how to solve the problem of the client. The client selects the contractors based on their expertise and experience, which often results the best possible solutions to clients’ problem. When a technically specified demand is applied, the client describes the technical requirements and how these requirements should be met. This is a more traditional way of construction. The client is often supported by a specialist to work out a first Program of Requirements (PoR) and formulate several product scenarios. The costs and benefits of the alternatives are considered in order to decide on the most suitable design (Geraedts & Wamelink, 2010).

Design

Once a choice has been made for a certain product, a designer (and possibly other architectural specialists) works out the scenario in more detail in the preparation phase. In this phase, the feasibility of the alternative (design)solutions can be tested and reconsidered. After sketching, the designs are worked out in more detail into a final design. The construction documents contains the drawings, descriptions, specifications calculations, time-plan, and other information which will be provided to the contractor as a basis for the construction. When the specifications are known and authorizations are granted, the project is tendered with aid of STABU or RAW-specifications. In general, the contractor with the lowest bid wins the tender.

Realization

This phase is divided into three steps: work preparation, execution, and hand-over. The realization of the project starts with the preparation of the construction of the contractor. The division of activities are defined in one or several contract documents between the contractor and the involved clients. This document lays out the scope and the possible risks of the project. client or the contractor selects one or more advisers to coordinate the preparation, execution and hand-over. The contractor is usually responsible for the execution until completion of the project. The realization phase ends with the hand-over of the product to the client.

Commissioning

This phase is also called operation or post-construction in other life cycle models. After realization, the constructed building is commissioned and managed. Maintenance is covered depending on the type of contract. This phase covers the longest period of building life cycle. After a certain amount of time, the construction may no longer meet the technical or functional requirements and could be declared unusable. In that case, preparations are made to demolish the building. After demolition, the land is available for new construction projects.

2.1.4 The logistics process

A construction project often involves a large variety of contractors that are responsible for delivering certain goods to the construction site. Deliveries are often done by different suppliers, including building material wholesalers, manufacturers, subcontractors and raw material suppliers. Figure 11 illustrates a general outline of deliveries to the construction site.

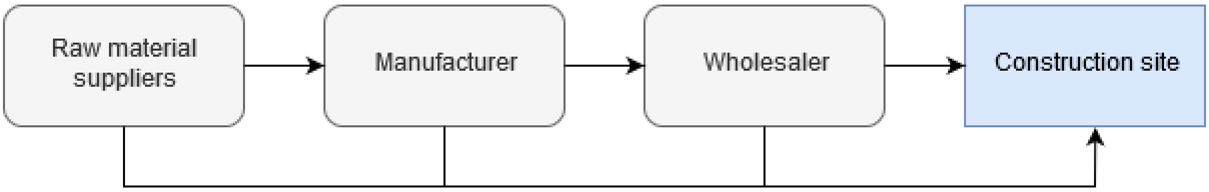

Figure 11 - Deliveries to the construction site, based on Ludema (2011)

The decoupling the supply chain can take place the use of transfer points or logistical hubs. There hubs are currently partially used in construction for interim storage on or nearly the construction site. Goods are unloaded and stored until further processing or assembly. As a result of the limited available space at or near the construction site, this form of hub is not always possible. In addition, a transfer point often causes considerable hindrance to the environment.

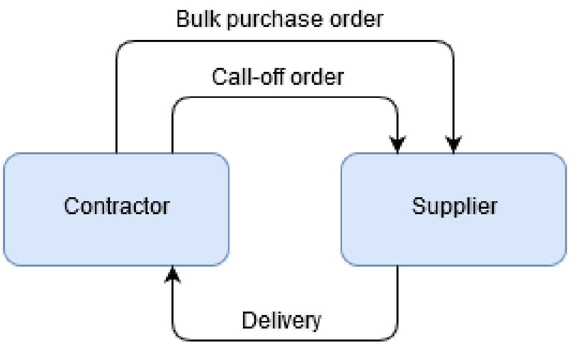

Figure 12 - Traditional control of deliveries, based on Ludema (2013)

Orders are placed based on the project schedule. Figure 12 shows the traditional way for contractors to order deliveries from their suppliers. The deliveries of suppliers may take place using the suppliers' own transport or that of a logistics service provider. The information of the order includes item code, name, the component, the contractor's weekly planning, etc. For the information exchange about the delivery of products to the construction site building tickets can be used. The building ticket is a form with which the supplier reports deliveries to the construction site in advance. The logistical coordinator can schedule the deliveries on-site. On the construction ticket information stated about the supplier, the carrier, the products, information about the goods and any handling requirements.

Construction Consolidation center

The typical construction consolidation center that is generally seen as the solution for most problems takes the form of a city distribution center to which suppliers deliver their goods. A construction consolidation center is a transshipment point that is conveniently located for suppliers at the edge of a city (Vries & Ludema, 2012). The goods are unloaded at the hub, are transferred to another means of transport or temporarily stored and after call-off delivered to the (sub)contractor at the construction site. The construction logistics hub thus acts as a decoupling point where deliveries from goods originating from multiple suppliers are "pushed" to the hub and "pulled" from the construction site. This makes deliveries to the consolidation center less time dependent than deliveries directly to the construction site. In addition, depending on the nature of the goods and the method of processing, the truck load of the deliveries to the construction site can be increased. However, this only work to a limited extent. Certain goods are not suitable for consolidation and need direct delivery, such as concrete mixers with liquid concrete, full load wagons or deliveries that requires special handling.

In addition to outflow to the construction site, it is possible to use the center for return flows as well. Figure 13 shows a schematic illustration of the primary delivery processes to the construction site using a construction consolidation center.

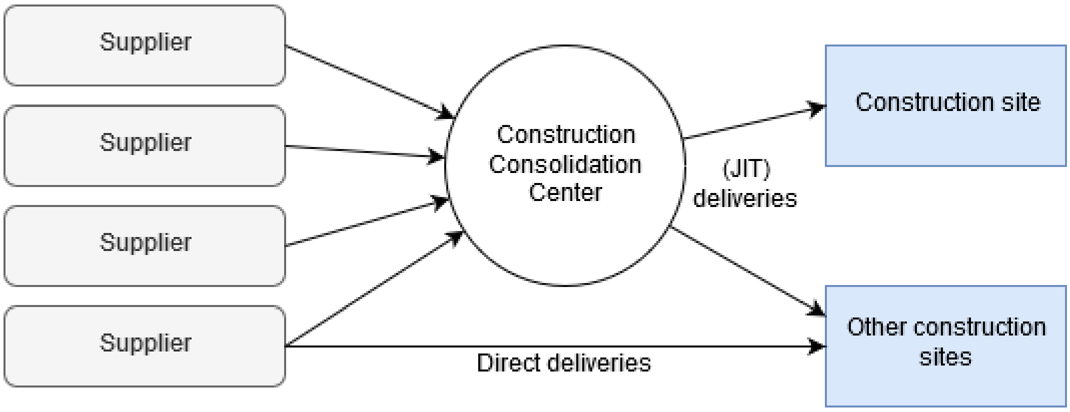

Figure 13 - Primary delivery process using a CCC, based on Ludema (2013)

Goods are ordered from the supplier by the (sub)contractor based on project planning. During the construction, a six week project planning is usually used in which each activity is clear per week. Insights about the activities performed on a specific day is usually provided in a more detailed week planning. The latter is leading for the call-off of goods at suppliers. Consequently, the suppliers deliver the ordered goods to the construction site.

With the use of a consolidation center, the goods are ordered by the contractor at the supplier, based on the project schedule. The supplier delivers goods in bulk to the construction consolidation center to be temporarily stored. The contractor can call goods daily from the consolidation center so that the goods can be delivered into a combined freight when they are needed at the site. The latter happens on the basis of detailed (day) planning. The orders are assembled and delivered within 24 hours. Figure 9 illustrates the control of delivery via a consolidation center.

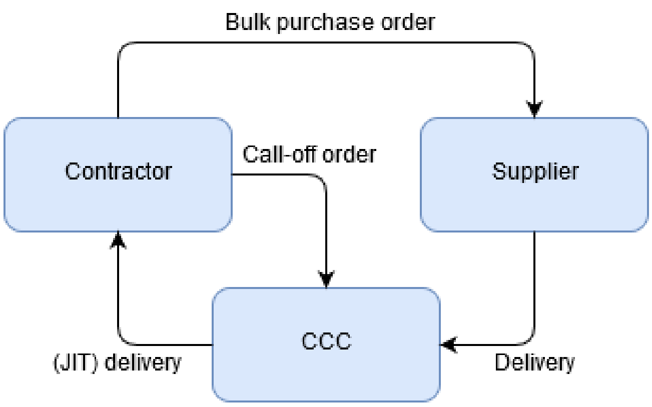

Figure 14 – Control of deliveries via CCC, based on Ludema (2013)

Benefits of a CCC

The construction consolidation center provides temporary storage space for suppliers' "push" deliveries and allows "pull" deliveries based on the construction schedule to be transported to the construction site. By packaging the goods in a certain way, the hub allows contractors to increase the capacity of trucks headed to the city center and to reduce the number of transports required (Vries & Ludema, 2012). Supplies can also be transported using smaller (electrical) vehicles. The benefit for the city is that it minimizes disturbances in the city center.

The LCCC (London Construction Consolidation Centre) is a successful pilot of a consolidation center for the supply of multiple construction sites in London. The use of a consolidation center has shown to reduce the number of transports (and therefore transport costs) significantly. The LCCC has a achieved a transport movement reduction of 65% which results in reduction of CO2 emissions by approximately 75%.

Vrijhoef et al. (2015) compared the performance of two pilot projects (De Trip in Utrecht and the Amtelkwartier in Amsterdam) using pre-defined KPIs. By using a construction consolidation center in combination with a logistics coordinator, deliveries could be scheduled in accordance to the needs on the construction site. Based on the analysis of the construction logistics concepts, the construction hub appears to offer great benefits to the construction process. As a distribution center on the outskirt of the city, it is easily accessible for carriers which can supply the construction site more efficiently. The advantages have been demonstrated on several occasions. Moreover, such a hub facilitates the use of other smart concepts. The establishment of a construction logistics hub has been described as a necessity in cases where construction takes place at busy locations with limited space, a high number of visitors and a need for ongoing accessibility. Despite some early setbacks, the De Trip project ran three months ahead of schedule once the hub was running at full capacity (Merrienboer, S.A. van & Ludema, M., 2016).

Table 2 shows the benefits that have been achieved by the London Consolidation and Utrecht CCC and the Utrecht CCC.

KPI	London CC	De Trip	Voorzetgebouw Paviljoen	Noordgebouw, Utrecht
Percentage over hub	100%	100%	15%	60-80%
Reduction in transport miles	68%	69%	47%	72%
Average load factor	-	90%	75%	81%
Time savings	2 hours	1 hour and 21 min	1 hour and 26 min	1 hour and 25 min
CO2 reduction	75%	68%	40%	87%

Table 2 - Benefits CCC London and Utrecht (VolkerWessels Bouwmaterieel)

The transport of goods via a construction hub results in a different cost structure. The transport costs can now be divided into a long haul to the hub and a short haul into the city. The hub is typically more accessible for trucks and remains open for deliveries longer than the construction site. Naturally, the hub itself gives rise to additional costs, consisting of overheads and operational costs. However, there are significant cost savings to be achieved, so the main challenge is in distributing these costs and benefits among stakeholders. The hub provided space for prefabrication, which meant the work on the construction site could proceed faster. Furthermore, the shuttle bus for workers ensured that the inner city construction sites were not overflowing with parked cars.

Requirements and disadvantages

Next to the aforementioned benefits, there are several disadvantages that need to be accounted for when establishing a consolidation center. The use of a consolidation centers has proven to have significant benefits. However, one also needs to take the drawbacks into account. First of all, the benefits of the CCC difficult to quantify in advance. The benefits will only gradually become apparent as the construction progresses. Opinions differ on when the use of the CCC is beneficial and how to fairly distribute the costs and benefits among the stakeholders (Vries & Ludema, 2012).

To successfully implement a construction consolidation center, collaboration between the most important supply chains partners is essential. Success can only be achieved if there is sufficient trust between participants and clear agreements have been made in advance about the role of the consolidation center. The parties that are typically involved in this are the contractors, suppliers, possible logistics service provider and the client. An important basis for achieving this is a workable underlying business model. A clear business model is needed to align the interests of the different parties involved. It is also important to involve and manage partners early in the process.

It must be clear who contributes to what during which phase in the construction process and what every party gains. Enough space must be available where the center can be realized. The terrain must be secured and have the appropriate equipment to handle the goods. Also, an information system must be available to control the flow of goods and logistics employees need to be appointed. The terrain can be open 24 hours a day for the delivery of goods and the scheduling of deliveries to the construction site(s). The operation of the construction consolidation center is therefore a costly operation (Vries & Ludema, 2012).

2.2 Cross Chain Control Centers

The aim of this study is to make a blueprint of a Cross Chain Collaboration Center (4C) for the construction industry. In order to come to a definition of what a 4C is, we have to go into the concept of control towers and supply chain collaborations first.

2.2.1 Control towers

Supply chain visibility is regarded as an important organization capability to improve decision-making and reduce negative impacts of supply chain disruptions (Barratt & Oke, 2007; Brandon-Jones, Squire, Autry, & Petersen, 2014; Dubey e.a., 2018). Supply chain visibility is described as “the extent to which actors within a supply chain have access to or share information which they consider as key or useful to their operations, and which they consider will be of mutual benefit” (Barratt & Oke, 2007). To create supply chain visibility, it is key that the information is timely, trustworthy, accurate and useful (Zhou & Benton Jr, 2007).

By introducing new supply chain management concepts, companies have sought to create this visibility and maintain a sustainable competitive edge. A new concept “Supply Chain Control Tower” has been proposed not only create supply chain visibility, but also to exercise certain control over the logistics flows.

Literature review reveals little academic research regarding the concept of “Control Tower” for supply chain visibility. The concept has mainly been used in non-academic publications by software vendors and consultancy firms (see for example: Bleda, Martin, Narsana, & Jones, 2014; Bosle e.a., 2011; Samelson, 2017). They often have their own definition of a control tower and load it with marketing hype which often leads to confusion and misinterpretation in the marketplace (Pradhan, Payne, & Titze, 2018). There are dozens of vendors solutions that are marketed as control towers with each their own capabilities, but here is no uniform description of a control tower listing standard capabilities.

Research and advisory firm Gartner (Pradhan e.a., 2018) takes a more critical approach and attempts to define the term “control tower” by describing three capabilities:

- <u>End-to-end visibility</u>
  Data is essential for end-to-end (E2E) supply chain visibility. Having access to accurate, timely and relevant data across organizations supports effective planning and execution of supply chain activities. Ultimately, the data should provide the supply chain with a single and accurate source of truth that can be used to support decisions. This data will come in at the right cadence from both inside as well as outside the supply chain. This

involves a network of interconnected systems (internal systems and external partner ecosystems) that is able to ingest and push data.

- Information hubs

  At heart of the control tower is the “information hub”. The integrates, gathers, stores and normalizes the data from a variety of sources and uses the appropriate logic and analytics to simulate impacts and measures across the supply chain. This information is distributed in a consistent format for further utilization by the supply chain parties.

- Digital twin

  The “digital twin” refers to a virtual supply chain that is updated in (near) real-time to reflect the physical supply chain. This digital twin provides a single source of truth for all partners to support decision-making and coordination and enables supply chain planning and execution functionalities.

The control tower supports end-to-end decision making of various levels of granularity through data driven insights from the supply chain. Companies can use a control tower for levels of control: operationally, tactically, and strategically.

- Operational level: this level concerns real-time planning and control activities. This includes order management, and issue and event management.
- Tactical level: this levels means that three months till three years. This enables proactive planning of procurement, operations and distribution. Carrier management, invoicing control, and transport optimization.
- Strategic: the control tower is used for the design of the overall business network.

Ultimately, the control tower is a digital supply chain platform that provides supply chain parties with relevant and accurate supply chain insights. This includes the use a range of interconnected computing devices (i.e., Internet of Things) and, to a certain degree, some intelligence (e.g. predictive analytics), to continuously learn, generate insights and provide recommendations. The control tower can be used in numerous ways to support the supply chain. Control towers are can be used to monitor and plan:

The control tower could provide supply chain parties new insights through interactive dashboards, geo maps, production workflows to visualize data (Pradhan e.a., 2018). Also, supplier performance can be monitored. The data could be used to plan, book and track the delivery of goods throughout the supply chain (Bosle e.a., 2011). The control tower could be embedded with predictive capability to predict the impact and probability of certain events on the supply chain to enable quicker responses (Bosle e.a., 2011; Pradhan e.a., 2018). At the operational level, predictions can be made about the estimated time of arrival of deliveries or forecasting supply chain costs and demand. A uniform model of the supply chain could drive simulations of certain what-if scenarios.

2.2.2 Cross-chain collaboration

A supply chain consists of a network of business collaborations involving two or more stakeholders that pool their resources (e.g., information, labor, money) to achieve a goal that is difficult to achieve individually (e.g. generate higher levels of productivity and revenue) (Gray, 1989). Two forms of supply chain collaboration can be distinguished: vertical and horizontal (see Figure 15). Vertical collaboration includes collaboration with suppliers, internal collaboration (i.e. across business departments), and collaboration with customers. Horizontal collaboration refers to the collaboration with competitors, internal collaboration, and collaboration with other organizations (non-competitors). In literature, the notion of lateral or cross chain collaboration is introduced to describe the concurrence of both vertical and horizontal collaboration (Simatupang & Sridharan, 2002).

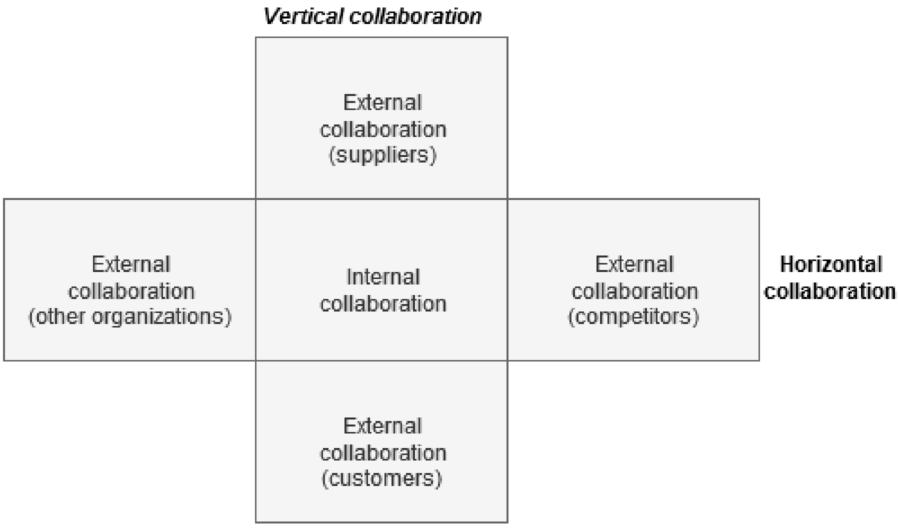

Figure 15 - Scope of collaboration (adopted from Barratt, 2004)

<u>Vertical collaboration</u>

Vertical collaboration involves collaboration with clients, contractors, etc. Here you can interpret collaboration in different ways; it could be about better information exchange with customers or suppliers or coordinating delivery moments with other links in the chain. Traditionally, supply chain management covers all links in the chain, except the transport links. According to TNO, transport is often (wrongly) seen as a ‘commodity’ that is never scarce. This assumption means that the supply chain will be sub optimally managed, because in order to achieve an optimal result, all links in the chain must be giver attention.

Horizontal collaboration

Horizontal collaboration occurs among businesses that are on the same position in the chain. Examples of this kind of collaboration include, collaboration among logistics service providers and collaboration among shippers. Horizontal collaboration is often difficult to achieve, because in many cases it involves collaboration with competition. in which all sorts of issues arise. After all, competition law permits companies to serve a large part of the market from a joint venture.

2.2.3 Defining Cross-Chain Control Centers

There is very limited scientific research on the 4C concept explicitly and practitioners, industry experts and consultants each hold their own views and definitions. The term Cross Chain Control Center (4C) was first coined by Van Laarhoven (2008). It can be described as a control tower that oversees the flow of goods, information, money across multiple supply chains (both for vertical and horizontal supply chain collaboration). The concept of a central control towers to manage multiple supply chains has studied by several authors (see Dalmolen, (2011); De Kok e.a. (2015); Grefen & Dijkman (2013)). This thesis adopts the following definition as formulated by (De Kok e.a., 2015):

"A 4C legal entity performs supply chain management (SCM) or supply chain execution (SCE) activities, granted this responsibility by more than one legally independent partner in one or more supply chains"

According to this definition, the 4C is a service provider to participants of one or multiple supply chains. A 4C operates mainly on the tactical and strategical level to establish and support collaborations between the participating parties. By centralizing the coordination control, it is able to harness the full potential for synergy resulting from cross-chain collaborations. Figure 16 illustrates the 4C place across the multiple supply chains in order to provide its services.

Thus far, the 4C concept has mainly been described in fast-moving consumer goods sector as central actor (trusted third party, or trustee) that mediates between carriers and shippers to share transport capacities. It connects multiple supply chains to allow multiple shippers to develop a logistical strategy to enable collective benefits.

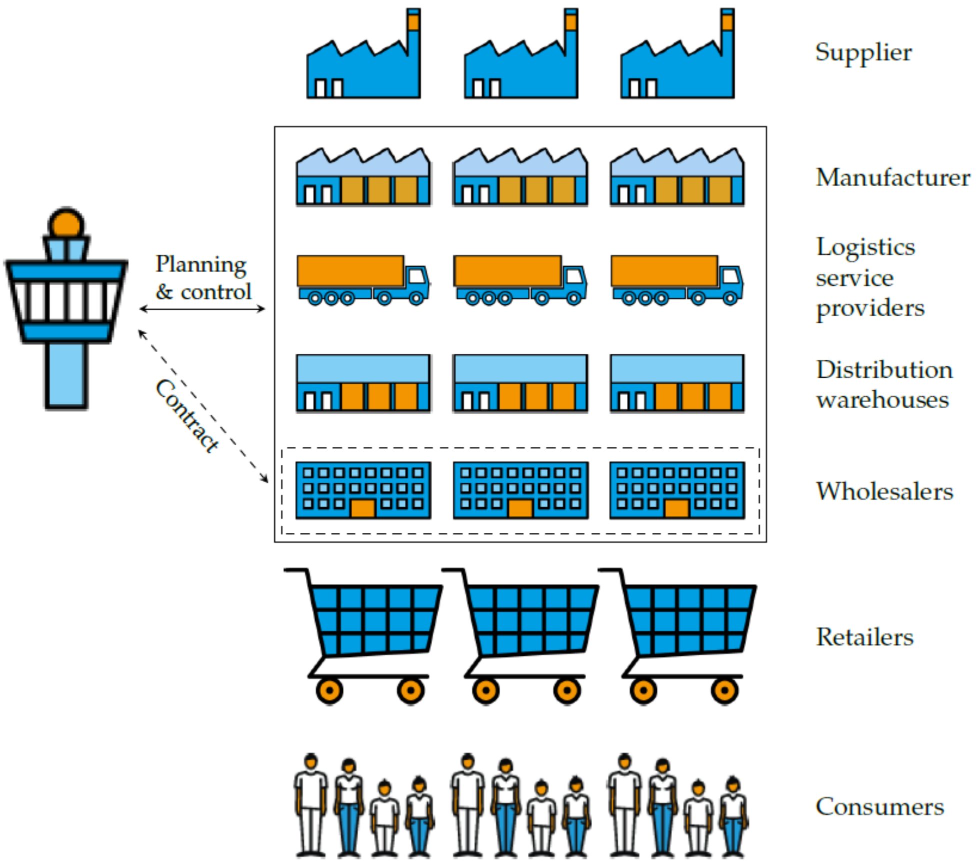

Figure 16 - 4C supply chain network coordination, copied from De Kok e.a. (2015)

Dinalog argues that Cross Chain Control Centers are needed to coordinate the collaborations between logistics service providers to make logistics more sustainable (Clausen, De Bock, & Lu, 2016; te Lindert, 2013; van Hillegersberg, Moonen, & Dalmolen, 2012). They describe a Cross Chain control tower as a neutral platform for firms to coordinate their cargo flows. The control tower plans and monitors the flow of goods, finance and information of participating supply chain parties using smart ICT solutions. Consequently, transport capacity can be bundled, loading capacity can be increased and the number of transport kilometers can be reduced. This reduces CO2 emissions and lower logistics costs.

The TNO describes the 4C as a control center from which multiple supply chains can be simultaneously coordinated using state of the art technology, advanced software concepts and supply chain professionals. This coordination is made possible through numerous information sources. The information that becomes available for the control tower could help manage the supply chains in more efficient ways. The increased transparency that comes from using the 4C allow supply chains to better respond to changes, which makes the supply chains more robust. Furthermore, the 4C makes a strong contribution to social objectives, such as environmental concerns. By managing transport more efficiently between parties, traffic congestions, pollution and transport costs can be reduced.

2.2.4 Network governance models

An important question is the role of the participating supply chain actors and who operates the 4C. There is no definitive answer. The 4C requires a careful established governance model (Dalmolen, Moonen, & Hillegersberg, 2015).

There are three types of interorganizational network governance models (Provan & Kenis, 2008). Provan and Kenis define the term *network* as a "group of three or more legally autonomous organizations that work together to achieve not only their own goals but also a collective goal". The authors make a distinction between a participant-governed (i.e., shared) network, a lead organization, and a network administrative organization.

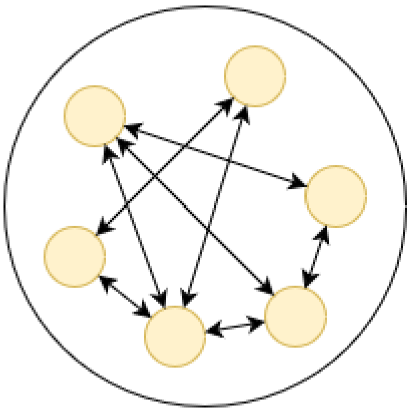

Figure 17 - Participant-governed network

Participant-governed network

A shared network is the simplest form of network governance (Figure 17). This form does not involve a separate and unique entity to govern the network. Instead, the network is governed by the members themselves. The network is highly decentralized with members interacting with one another on a relatively equal basis. These interactions can be both formally and informally (for example, through regular meetings). This type of network requires the involvement and commitment of the participants as they themselves are responsible for managing the operations and the internal and external relations of the network. Due to the high reliability on other members, the shared governance is often seen in smaller strategic alliances and partnerships. Sharing the network governance means that the partners themselves manage network activities and make the decisions. Power among the network participants is more or less symmetrical, despite the organizational differences in structure, size and capabilities.

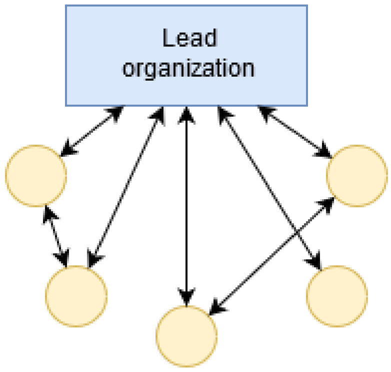

Figure 18 - Lead organization-governed network

Lead organization-governed networks

There may be situations where inefficiencies in shared governance calls for a more centralized approach. An extreme form of centralized governance is a lead organization (Figure 18). This form can typically be found in vertical relationships involving a buyer and a supplier that differ in power and size. This form can also be found in horizontal relationships where a single organization has enough legitimacy and capabilities to govern others in the network. A lead organization is a single participating member that manages major network-level activities and takes key decisions to coordinate other members.

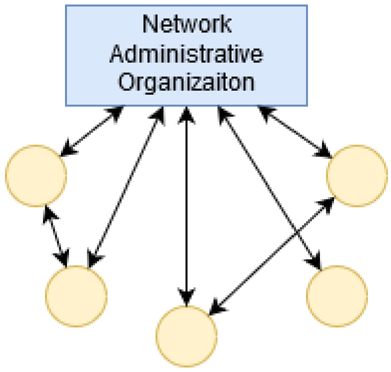

Figure 19 - Network Administrative Organization-governed network

Network administrative organization

The Network Administrative Organization (NAO) model is a form of network governance that involves a separate entity that is specialized in network governance (Figure 19). This entity is not a member of the network providing its own services, but an external network broker that coordinates and sustains the network and its activities. NAOs may be established by the members themselves or through mandate for the sole purpose of governing the network. NAOs are generally modest in scale and are most likely either a government entity or a non-profit organization. These entities have to ensure that certain network goals are met that have been collectively agreed to. Formalized non-profit NAOs typically have a board structures that comprises other members in the network (Provan, Isett, and Milward, 2004).

Some logistics experts believe that the 4C should be a neutral third party that is trusted by all parties in order for horizontal collaboration to succeed (Jongens, 2013; Pals, 2017; Lindert, 2013). Question remain about how neutrality can be guaranteed and to what extent this entity is able to exercise control in a way that benefits all parties. This is still a grey area.

2.2.5 4C information architecture

Highly dynamic business networks involving specialized and geographically dispersed actors are not able to function effectively without proper IT support. According to (Dalmolen e.a., 2015), the feasibility of a 4C control tower is dependent on an effective IT architecture that enables collaboration among supply chain partners. Proper supply chain integration can be supported by linking supply chain information systems of individual organizations. Over the years, the increased focus on supply chain integration has led to an increased shift in attention from traditional information systems (IS) to interorganizational information systems (IOS) (Robey, Im, & Wareham, 2008). Robey e.a. (2008) defines interorganizational information systems as “automated information systems, shared by two or more organizations, and designed to link business processes”. Traditional IOS support of SCM have mainly involved static integration of systems. Although this has led to significant improvements in supply chain efficiency, creating these links between IS among partners has been found a cumbersome task due to the technical complexity of connecting legacy systems. Efforts of inter-organizational system integration have often resulted in "hard-wired" links do not allow business processes to quickly connect with business partners, and thus do not lead to agile business networks. (Grefen, 2006; Kumar & Van Hillegersberg, 2000, 2004).

The focus of the 4C should be on ICT support for agile business network integration. The platforms is different from traditional ICT connections as the 4C services are enabled through a virtual “cloud”. This virtual cloud should be scalable and be able to quickly link up business processes (Grefen e.a., 2009; Van Hillegersberg e.a., 2004).

Control across supply chains

Literature review reveals several IT architectures possible for supply chain-wide information and control (see examples in Grefen & Dijkman (2013)). In this thesis, we focus on architectures taking into account logistics chain concurrence as many firms can take part in part in multiple supply chain configurations simultaneously (O'Brien e.a., 2008; Verdouw e.a., 2011).The concept of 4C has been introduced to support both intra-chain (i.e., within a single supply chain) and inter-chain (i.e., across multiple supply chains) collaborations.

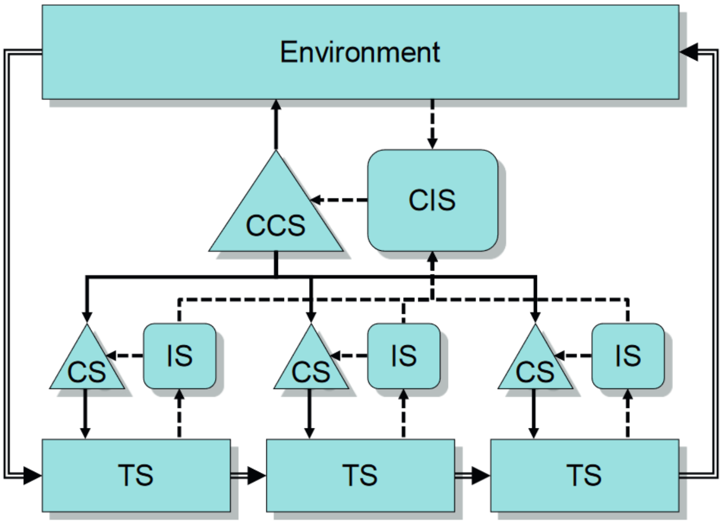

Figure 20 - Hybrid control model, copied from Grefen & Dijkman (2013)

At the intra-chain level, a hybrid form of centralized and decentralized control is possible (Figure 20). Operational control is managed through direct bi-directional integration among the partners themselves. The information for information systems (IS) of the different parties are fed by their respective transformation systems (TS). The TS records the events from the environment, such purchase orders or work orders. The parties use the information aggregated by the IS for their control systems (CS) to make new transformations that is send to other parties, such as sending a transport order. The monitoring and analyzing of data from the environment may require the IS and the CS to use advanced algorithms and communication technologies, such as remote sensors and decision-support tools.

Tactical and strategic control is done by a central actor. The central CS (CSS) and central IS (CIS) represent a central actor for information and control (e.g., a lead organization or NAO). On this level, chain-wide insights can be gained and used to steer the CS. For example, the CCS may decide to manage the stock levels of the parties in a way that minimizes total stock levels. Or, the CIS is used to create forecasts based on the information from the IS of the involved parties. It is important to note that CS does not necessarily have to be both centralized. The central actor may only the CIS, while the CS remains with the participants. An example is a control tower that provides participants with real-time traffic information.

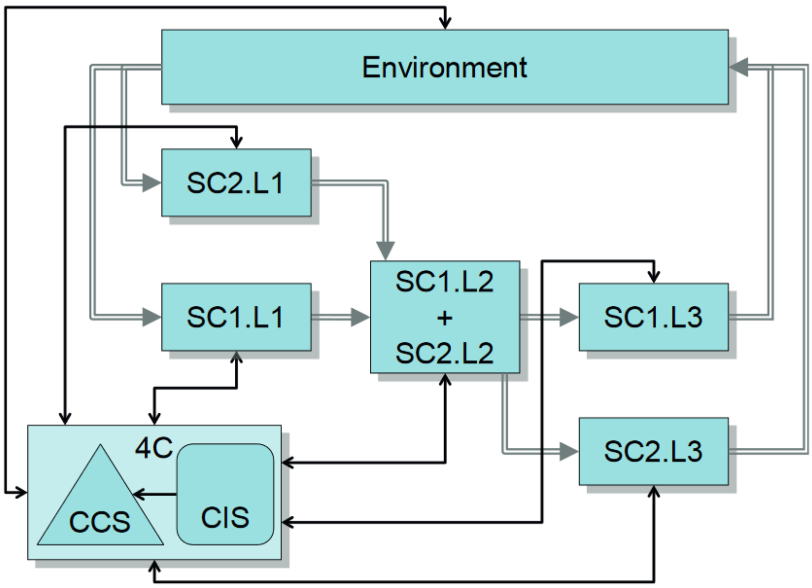

Figure 21 - 4C integration model, copied from Grefen & Dijkman (2013)

As the name suggests, a 4C provides control services across multiple supply chains. The described hybrid model is not only possible at the intra-chain level, but also the inter-chain level. Figure 21 is an abstract illustration of the supply chain links through a 4C. Both the CSS and the CIS has been merged into a black box for simplicity. In reality, it is important that control does not necessarily have to belong with the 4C at this level There are various configurations of information and control possible the enable inter-chain and intra-chain collaborations. One could imagine a three level control model (individual enterprise level, intra-chain level and intra-chain level), where certain information and control is delegated to specified actors at each level. In this figure, the 4C controls the individual supply chains (SC1 and SC2) as well as both supply chains simultaneously (SC1 + SC2). L1, L2 and L3 are the links between the two chains. The chains that concur share the same link (L2).

2.2.6 Requirements and challenges

Of course, the reality of collaboration and competition in business networks must be taken into account. There different advantages and disadvantages with regard to trust and power. According to Lindert (2013), the biggest obstacles of control towers are the lack of trust, fair sharing mechanisms and intelligent IT tools.

The inter-firms relationships in an agile business network requires clear governance. Several key capabilities need to be taken into account to achieve this network (Dalmolen e.a., 2015):

- Modularization: a modular structure simplifies the integration, composition and coordination of business processes (Tanriverdi e.a., 2007). This means that products and services, as well as the processes supporting them, are a set of independent modules that can be mixed and matched in a variety of configurations. Modularization also helps to specify and assess the quality of the offerings and enables better target pricing (Hoogeweegen e.a., 1999)
- Coordination and collaboration: the coordination of a complex multi-actor network such as in logistics collaborations requires various protocols, tasks and decision-making mechanisms. Although optimizing interwoven supply chains could provide significant benefits (e.g., dynamic resource sharing), it is difficult to achieve on a high level. The 4C will have to ensure that optimizing one chain does not de-optimize the other. There are three mechanisms of control in business networks (Dekker, 2004): (1) control of outcome by incentive systems, performance monitoring and rewarding; (2) behavior control by planning, rules, regulations, monitoring and rewarding; and (3) social control by partner selection and trust building.
- Quick connect: the 4C control tower functions as a hub for a dynamic business networks consisting of a range different participants. A solution for inter-organizational collaboration should be able to quick connect individual services, handle complex inter-organizational functionalities, and allow individual services to disconnect without disrupting remaining services (Aulkemeier, Iacob, & van Hillegersberg, 2019). An important capability to enable pluggability of services is API management. An API or web service interface could be used by the client to access the core data (For more information, see Aulkemeier, Iacob, & van Hillegersberg (2019); Aulkemeier, Paramartha, Iacob, & Hillegersberg, (2015)). These quick connect capabilities should not only be possible on a technical level, but also on the business contract level.

- Relationship management: 4C control towers attempt to manage agile business networks where partners only have limited time to build trust. In practice, only a few examples of a central actor for supply chain control in logistics can be found. A central authority is not likely to be accepted by other powerful actors (Kumar & Van Hillegersberg, 2000). Information is more likely to be exchanged if joint benefits can be gained and equally shared. Mechanisms should be in place to ensure loyalty in a business network where trust cannot be based on past performance and long-term relationships. Capabilities such as formal communications and conflict resolutions should ensure a higher performance of inter-organizational collaborations.
- Risk management: dynamic inter-organizational collaborations are risky undertakings for participating parties on both the technical and organizational level. High quality technical and organizational semantic standards should be in place to avoid the risk of misunderstandings (E. J. A. Folmer & Verhoosel, 2011).

3. 4C business model design

In this chapter, a design is made of a 4C control tower for construction supply chain management. The business logic of the 4C is explained using a business model framework selected in section 1.5.

3.1 Construction Cross Chain Control Center

The 4C control tower is an information hub within the construction supply chain that focuses on providing end-to-end supply chain visibility and control for multiple construction projects.

The 4C control tower is an agile cloud platform that integrates existing ERP, WMS, and TMS systems of suppliers, subcontractors, logistics providers and other partners to gain full visibility in the supply chain. The information exchange among the parties, including the available data, is visualized in visualized in Figure 22.

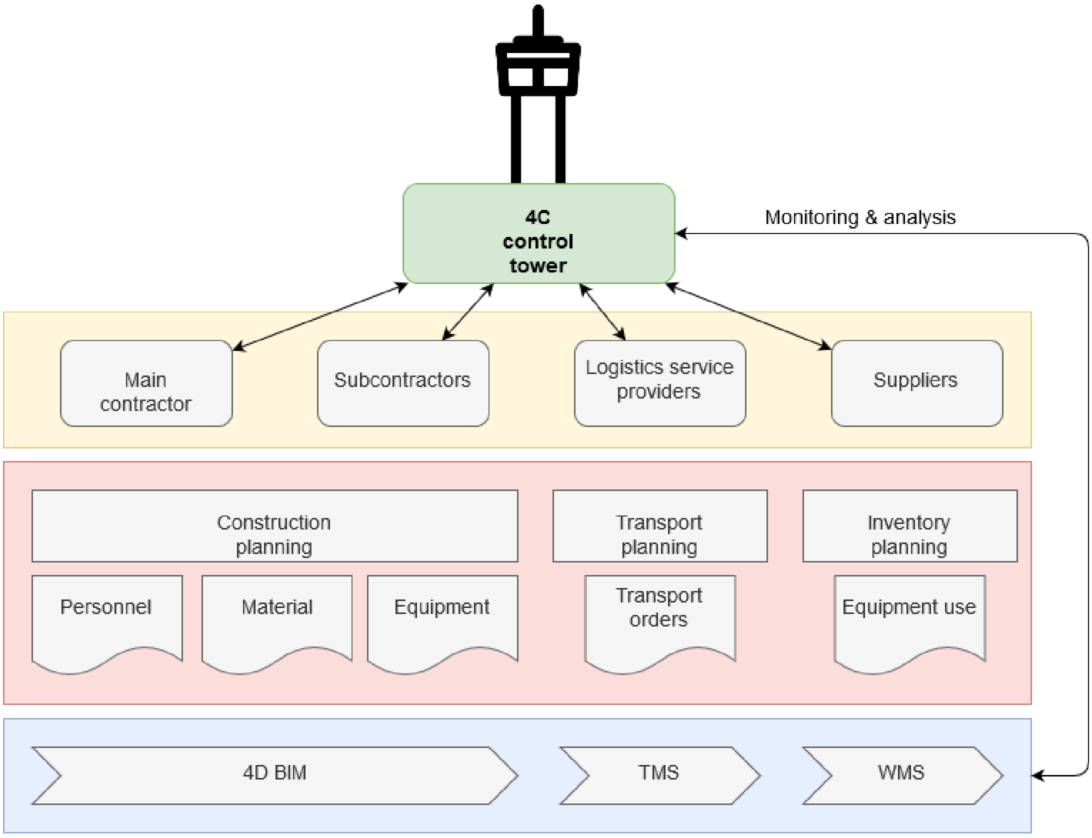

Figure 22 - 4C control tower in construction

The figure visualizes the information exchange for one project operated by one contractor, but one could imagine parties of multiple projects to exchange information with the 4C. The 4C control tower monitors, measures, manages transport and inventory movements across the construction supply chains in coordination with the construction planning of construction sites of its clients. Between the 4C and its clients, value is exchanged through feedback and advisory services.

A control tower can take different forms in terms of scope of control and functionalities (Bleda e.a., 2014). The design and role of the control tower in the supply chain is dependent on the needs and capabilities of the supply chain. Similar to existing control towers, a 4C control tower would aim to improve the collaboration of its clients and advance the supply chain management by integrating the relevant technologies and systems to a common environment.

This thesis views the 4C control tower as a virtual/digital construction consolidation center considering the 4C 'consolidates' data from different parties within the construction supply chain and uses the data to provide coordination services for its clients. Similar to a physical CCC, a 4C control tower may operate as an independent entity to support the logistics process of multiple contractors. To execute the logistical supply chain activities, the 4C control tower can be used in combination with a physical construction consolidation center or a logistics provider. The management activities of construction consolidation centers are mainly operational (e.g. loading and unloading of goods, storage, pre-fabrication) and are limited to the projects constructed within a certain target area. A 4C control tower can theoretically extend this to provide visibility and control of goods across projects that use different consolidation centers or projects that do not use consolidation centers at all

3.2 Business model

3.2.1 Customer interface

The idea behind a 4C is that it supports the coordination of a business network. In the context of the construction industry, we view a 4C as a service provider for the actors involved in several construction projects. The client network of the 4C control tower comprises the five key stakeholders involved in the realization of a construction project. These include the general contractors, subcontractors, suppliers, carriers, and city councils.

General contractor

The general contractor oversees the building process and ensures the project is completed according to the requirements of the client. In general, the decision to use any logistical solution for a project lies with the general contractor. According to De Bes e.a., (2018), the general constructor currently has insufficient insight in the to-site and on-site logistical processes and is unable to leverage any potential optimization opportunities that may arise when information among supply chain participants is shared. Materials that arrive too early must be stored on site, which could lead to theft, damage and loss. If the building materials arrive too late, then construction process cannot continue on the construction site according to the building schedule. The general contractors use the 4C control tower to facilitate and foster collaboration with subcontractors and suppliers for an integrated building process.

Subcontractors

The general contractor generally outsources a large part of the construction work to specialized subcontractors. These contractors are responsible for a specific task (concrete floors, tiling, roofing sheets, painting, etc.) of a construction project. The involvement of many independent parties in a temporary organization has made coordination a complex and challenging task. The subcontractors use the 4C control tower to improve the collaboration with the general contractors, suppliers and other subcontractors. This helps contractors to allocate their resources more effectively and streamline the process in coordination with their partners.

Suppliers

The general contractor and subcontractors procure materials from a large number of suppliers (e.g. manufacturers, building merchants, wholesalers) for the realization of a building. The suppliers are unable to effectively manage their deliveries due to inaccurate and uncertain building planning and last-minute changes in the building process. These changes have made it difficult to carefully coordinate production and inventory. The suppliers use the 4C control tower to collaborate with contractors and other suppliers more effectively and improve the delivery of goods to the construction site in a more efficient way.

Logistics service providers

Logistics service providers deliver the goods from one party in the construction supply chain to another. While some suppliers and subcontractors use their own transport, other suppliers may outsource the transport to (specialized) logistics service providers. The construction site is dependent on a reliable delivery of goods in accordance with the main construction planning. An efficient delivery of material and equipment between the various suppliers, consolidation centers, and construction sites requires careful coordination. Carriers currently must deal with uncertainties in the requirements of the deliveries, limited site accessibility in cities, and unstructured communication with the suppliers and contractors. Additionally, carriers have to deal with low load factors, which is partly caused by urgent deliveries to various construction sites. As a central hub for building and transport planning, the 4C control tower is used by the carriers to better coordinate the delivery of goods with suppliers, (sub)contractors and other carriers.

City council/road authorities

With regard to the construction process, the main concern of the local governments, including the road authorities and city council, is the way it may affect the livability of the city. The city would use the 4C control tower to monitor the influence construction projects have on the environment (e.g. CO_2 emissions, noise, traffic congestion) via KPIs and regulate construction traffic in the cities. Careful traffic management in coordination with the construction process helps to better deal with bottlenecks in the city's infrastructure. For example, with help of traffic management systems, the 4C control tower may support in the use of traffic controllers in certain areas or allow for "green waves" for construction traffic to enable a continuous traffic flow over several intersections (De Bes e.a., 2018)

Channels

The channels are the means through which the 4C control tower communicates with its clients and distributes its services. Trade fairs, e-mail, press releases, and meetings with supply chain partners are among the many ways the use of the 4C among construction companies can be promoted. In case the use of a 4C control tower has proven to have significant economic and social benefits, some form of a control tower may become a requirement in public procurement contracts or tenders set out by the contractor.

The 4C control tower platform enables instant and seamless service provisioning and communication. Communication can be established using custom web API's to integrate the legacy systems of general contractors, subcontractors, logistics providers, and suppliers to the platform of the control tower. The control tower may also use a role-based cloud-based access control system to specify the roles and permissions of the participants. During the operation of the 4C, periodic reports on KPIs and other relevant information can be distributed through web portals and notification e-mails. Additionally, consultancy services can be provided online, over the telephone, and through personal meetings.

Customer relationships

Customer relationships are the set of value activities that are performed through the channels. Channels such as the web portals, telephone, e-mail or face-to-face meetings can be used for customer support and advisory services. Customer feedback can be provided by the clients to improve the 4C services and their delivery.

It is important that clients share the experience gained in order to improve and raise awareness of a 4C control tower. Both awareness about the 4C concept and a mental shift is needed among the involved construction parties to share information for the benefit of the whole supply chain. Serious games show stakeholders the opportunities and effects of collaborative planning (Katsma & Dalmolen, 2013) and has proven to be an effective way to stimulate awareness and mental shift (Susi, Johannesson, & Backlund, 2007).

3.2.2 Product

The cause of cost overruns and schedule slippages in construction projects can be attributed to the problems and inefficiencies in the construction supply chain, including lack of communication, insufficient and uncertain planning, and changes in product requirements. The 4C control tower brings value the whole business network of a construction project through improved supply chain performance (De Kok e.a., 2015). It support its clients to meet the project's requirements regarding cost, time, and quality. This is also known as the "iron triangle" (Atkinson, 1999).

Facilitating and fostering collaborations

According to (De Kok e.a., 2015), a 4C facilitates and fosters collaborative relationships among supply chain actors resulting in improved economies of scale and economies of scope. Economies of scale can be achieved by consolidating activities with supply chain partners. On a strategic level, economies of scope can be achieved by forming alliances with complementary organizations across different supply chains. The 4C can facilitate collaborations that reduce the overall costs in the supply chain, improve service levels and fulfillment, and reduce impact on the environment. In turn, implementing mechanisms for a fair allocation of benefits, costs, and risks ensures the long-term success of the collaborations (De Kok e.a., 2015; te Lindert, 2013; Vanovermeire, Sörensen, Van Breedam, Vannieuwenhuyse, & Verstrepen, 2014).

Enabling safe data exchange

The 4C control tower offers an ICT infrastructure to aid in the data sharing among clients. Unstructured and insufficient communication is a challenge throughout the construction supply chain (O'Brien e.a., 2008; Serpell & Heredia, 2004). Information that is exchanged among construction supply chain actors includes, among other things, construction planning, work orders, building product specifications (BIM), invoices and any changes that may arise during the construction process. As a central information hub, the 4C control tower enables the exchange of data and guards against unintended spill-overs of competitive information to ensure legal compliance (De Kok e.a., 2015).

Exploiting supply chain synergies

The 4C control tower provides unique services to its clients that exploit operational and strategic synergies that arise in cross-chain collaborations (De Kok e.a., 2015), including consolidation planning among carriers and suppliers, route planning between actors, and the synchronization of on-site delivery planning and the crane planning. These services help streamline the overall supply and construction process, improve predictability of transport, reduce transport costs, and allows for fact-based decision-making.

The 4C control tower as envisioned in the TKI-project "4C in de bouwlogistiek" mainly focuses on planning, coordination and monitoring of transport movements. These functionalities have to ensure a smooth supply of goods to the construction sites in line with the just-in-time principle. Just-in-timed delivery has to ensure that goods and materials are delivered in time so that they can be processed immediately.

The following business functions have been identified:

- <u>Horizontal transport planning</u>
  The 4C should be able to plan the most efficient way of transporting goods from one place to another. It determines which carrier transports what material to what location based on the construction schedule as well as the transport planning of the different suppliers and carriers. The 4C manages both forward logistics (i.e., the transport to the construction sites) and reverse logistics (i.e., the transport of waste from the construction site to a place for reuse, recycling and returns).
- <u>Vertical transport planning (e.g. crane planning)</u>
  The 4C should be able to plan the most efficient way of transporting goods by crane from one level to another. The 4C determines what materials are to be transported at what time and to what level. This can be done in coordination with the horizontal transport (i.e., dynamic synchronization) to ensure materials are moved to the appropriate location as soon as they arrive on-site.
- <u>Planning of delivery time windows</u>
  The 4C should be able to plan the optimal time for delivering goods at (un)loading sites. Deliveries at construction site(s) and consolidation hub(s) can be monitored and coordinated using delivery tickets for carriers and suppliers. The planning takes the current construction planning as well as transport planning into account.
- <u>Consolidation planning</u>
  The 4C plans the bundling of goods originating from different suppliers to increase the load factor of trucks, reduce congestion, and reduce overall cost of transport. The 4C determines which goods can be consolidated at what location in coordination with the daily planning of the construction site. The specifications of the material, including the

weight and size, can be determined from the Building Information Model (BIM). The 4C can also coordinate the bundling at source location with suppliers that are in close proximity of one another.

- Preferred route planning

  The 4C plans the most efficient route for carriers to transport certain goods from one place to another. Route planning reduces fuel consumption, traffic congestion, and CO2 emissions (Miao, 2018).
- Real-time monitoring of goods and transports

  The 4C allows participants to monitor the location of certain goods, stock levels, and the location of trucks (using floating car data) to estimate the arrival time deliveries. Other indicators that may affect road or crane transport can be monitored, including daily weather forecasts (wind speed), traffic bottlenecks or traffic measures.
- Provide periodic performance monitoring (daily or weekly)

  The 4C allows clients to monitor the performance of the construction logistics process using pre-selected KPIs, such as: transport journeys, kilometers, CO2 emissions, load factor, and more.

The 4C control tower described in the “4C in de bouwlogistiek” report mainly focuses on the transport of goods to the construction sites. Based on the literature on control towers, he functionalities can be extended to support other supply chain activities that are performed during a construction project.

- Simulations and what-if scenarios

  Simulations and what-if scenarios provide insight into the implications of certain logistical measures or solutions and can support the decision-making of contractors (Bleda e.a., 2014; De Bes e.a., 2018). For example, this could help to estimate the impact of sourcing material from an alternate supplier that has a higher price, but a shorter lead time; the impact of realigning inventory from hub to construction site; or the impact of certain adjustments to the construction planning. Consequently, the 4C control tower could manage the sourcing and order processes between supply chain actors based on these insights (Bosle e.a., 2011).
- Financial functionalities

  The 4C can include financial functionalities, including debt management, investment pooling and reverse factoring (Van der Vliet, Reindorp, & Fransoo, 2015). Reverse factoring has shown to improve transactional efficiency of clients by reducing excessive factoring as a result of indivisibility. It also improves liquidity by allowing firms to finance lucrative investments using the value of non-cash assets.

3.2.3 Infrastructure

The infrastructure segment consists of the internal and external organization of the 4C control tower that allow it to create value for the customers. The infrastructure block consists of the key activities, key processes, and partner network.

Key activities

The following key activities have been identified:

<u>Network coordination</u>

Network coordination for construction projects is the key process and competence of the 4C control tower (De Kok e.a., 2015). Network coordination encompasses transport and warehouse management activities such as the coordination of deliveries to the various construction site or consolidation centers. The 4C can help lower costs, improve service levels, and improve environmental impact by consolidating and synchronizing the delivery of goods to the construction sites. It does so by providing the relevant actors information as to what goods are to be delivered, to what place, at what time and by whom. It hereby takes the construction planning, transport planning as well as the current stock levels at the suppliers, construction site and consolidation centers into account. The pooling of resources and consolidation of transport goods improves the network density and supply chain performance (Akintoye & Main, 2007; Chopra & Sodhi, 2014).

<u>Alliance management</u>

The sharing of resources, such as the bundling of goods for one carrier, is a collaborative effort that requires careful management to ensure long-lasting value creation. This is especially true if it involves competitors (Wilhelm, 2011). The 4C is tasked with the formation and management of collaborative alliances among client firms. The alliance lifecycle can be managed through a structured step-based approach involving design, management, evaluation, and termination (Tjemkes, Vos, & Burgers, 2017). The 4C can support alliances by partner selection, safeguarding confidential data exchange (De Kok e.a., 2015), and the fair allocation of costs and benefits among client firms (Vanovermeire e.a., 2014). In addition, the 4C can expand the client network through acquisition and retention activities. The 4C can also educate firms on developing alliance capabilities, including alliance evaluation, bonding and trust development, and knowledge sharing, to work together more effectively (De man, 2015; Kohtamäki, 2018).

Administrative activities

Next to the coordination services, the 4C performs administrative activities that support the management of the construction projects. These activities include invoicing (following the SALES standard), the handling of (work) orders, and debt and credit settlements among the clients. In addition, the 4C can support or facilitate more advanced finance-related processes, including investment pooling and supply chain finance factoring (Van der Vliet & Rendorp, 2015). Other activities include legal assistance, communication and public relations and sales support (Jannsen et al., 2015). On an operational level, an advanced form of a control tower can become mostly autonomous to handle daily operations. On a more strategic level, the control tower uses a skilled workforce can provide non-operational support and ad-hoc analysis (De Kok, 2015).

Key resources

The 4C control tower consists of several key resources in order to create value for the clients.

Personnel

A 4C is regarded as a combination between an IT company and a consultancy company (Verstrepen, 2015). A 4C typically requires high-skilled personnel to operate and navigate multiple supply chain processes (Jannsen et al., 2015). The 4C personnel should possess a mix of hard and soft skills in order to perform alliance and coordination processes and use the IT for communication and decision-support.

ICT-infrastructure

Information technology is key to enable effective network coordination (Skipper et al. 2008; Jansen et al, 2015). The 4C control tower needs an extensive information system architecture linking Enterprise Resource Planning (ERP) systems, transport management systems (TMS), warehouse management systems (WMS) in order to have end-to-end visibility in the supply chains of the construction projects and improve decision-making. The 4C can use its comprehensive predictive analytics capabilities to create and improve forecasts, planning, and decision support. The infrastructure should enable plug-and-play services and a flexibility to ever-changing supply chain needs (Akkermans et al., 2003).

Key partners

There are several key partners that help the 4C in creating value for the customers: including hardware/software providers, advisory/consultancy firms, and research institutes One of the key partners for setting up and maintaining the 4C control tower includes the providers of hardware components, such as computers, sensors, servers, and mobile devices, and providers of software to run the control tower (Alias, Goudz, Jawale, & Noche, 2015). According to (De Kok e.a., 2015), the 4C could develop itself as a knowledge broker in a network of complementary advisory/consulting firms and become a channel for clients to make inquiries about topics such as, project management, HR, finance and regulations, could be exchanged. A 4C control tower can establish a strong link with research institutes to boost research and innovation in construction supply chain management (Alias e.a., 2015).

3.2.4 Finances

The finance block consists of the revenue streams and cost structure.

Revenue streams

There are several ways in which the 4C can seek reimbursement for its management and execution services (De Kok e.a., 2015). The 4C can charge a periodic monthly fee for parties involved in a construction project to participate in the client network. There may be multiple types of service for which the 4C can be independently compensated, including data storage (hosting fees), analysis, consultancy, or system maintenance (Alias e.a., 2015). Alternatively, the 4C can choose to charge for every transaction, e.g. for every order executed through the system or alert to the client.

Assuming the 4C is a for-profit center, there are several factors influencing the profitability of the 4C. The 4C will be better able to create, deliver and capture value to its target customers, the larger the network is. While the 4C control tower could, at a basic level, coordinate the supply chain management of a single construction projects as an independent network, an at-scale 4C control tower comprising stakeholders of multiple construction projects significantly increases number of transactions. This, in turn, increases the profitability and allows the 4C to develop a competitive edge.

Another policy choice is the target margin level. A break-even point will have to be determined based on the turnover per transaction or per period. A profit surcharge can then be added to the fee to achieve desired profit levels. Alternatively, the 4C can aim for future profits and temporarily charge a fee below break-even point. This lowers to the risk for clients to try the 4C services and allows the 4C to gain market share (De Kok e.a., 2015).

Cost structure

The costs of the 4C control tower highly depends on the services it provides to the client network. Intermediary, asset-light models typically have relatively low indirect costs and high direct costs associated with the network coordination (De Kok e.a., 2015). A comprehensive 4C control tower would require investments in human resources to set up and operate the 4C and underlying IT infrastructure to support the coordination processes. Acquiring the specialized software necessary for the 4C operations is generally a make-or-buy decision. The direct costs of a control tower mainly consists of software development and hardware acquisition, and costs for operation, infrastructure and analysis (Alias e.a., 2015).

<table>
<tr>
<td colspan="2" rowspan="2"><u>Key partners</u>

Hardware/software providers

Advisory/consultancy firms

Research institutes</td>
<td colspan="2"><u>Key activities</u>

Network coordination

Alliance management

Administrative activities</td>
<td colspan="2" rowspan="2"><u>Value propositions</u>

Facilitating and fostering collaborations across supply chains.

Enabling safe data exchange

Exploiting supply chain synergies</td>
<td colspan="2"><u>Customer relationships</u>

Client support and advisory services

Client feedback

Serious games</td>
<td colspan="2" rowspan="2"><u>Customer segments</u>

Key stakeholders
Contractors
Subcontractors
Suppliers
Logistics service providers
Local government</td>
</tr>
<tr>
<td colspan="2"><u>Key resources</u>

Personnel

ICT-infrastructure</td>
<td colspan="2"><u>Channels</u>

Trade fairs
Telephone
Emails
Face-to-face meetings
Web portals (web services)</td>
</tr>
<tr>
<td colspan="5"><u>Cost structure</u>

Human resources

ICT

Marketing</td>
<td colspan="5"><u>Revenue streams</u>

One-off fees (e.g. per transaction)

Recurring fees (e.g. monthly)

Complementary services: hosting fees, analysis, advisory services</td>
</tr>
</table>

Table 3 - 4C business model

4. Validation

4.1 Expert interviews

This study was conducted to explore the possibilities of a 4C control tower to support the management of multiple supply chains in the construction industry. For this research, several industry experts are invited to share their view on the 4C control tower. A list of the interviews can be found in Appendix A.

The experts are selected based on their backgrounds to ensure a wide range of different views. The interviews are conducted either on location of the interviewee, via Skype or by phone depending on what is most convenient for the interviewee. The interviews took between 45 minutes to 90 minutes. The interviews where semi-structured by nature to explore the construction logistics concepts and the role ICT could play in more detail. The interviews were set up to explore the different needs, the information flow, and the processes for inter-project logistics coordination to come to a more detailed business model.

4.2 Stakeholder problems and needs

The business logic of the 4C entity as described in the business model has been discussed with industry experts. The needs of the stakeholders are identified with regard to a 4C for construction logistics to validate the value proposition of a 4C control tower. The main findings of the interviews are presented in this subsection.

4.2.1 Problem definition

There is a need for better insight and control over the logistics of multiple construction projects, especially in inner cities. The following problems where mentioned by the experts:

Currently, optimizing the transport of goods is often not taken into account in the construction process. In many cases, parties are responsible for their own logistics and communicate insufficiently about what, how and when certain goods arrive at the construction site. According to one respondent, parties are not held accountable for their order behavior.

The difficulty in resolving lies in the unpredictability in supply from the suppliers and demand from the construction sites. External factors such as weather and traffic congestion can have severe consequences for both the on-site and the supply logistics. This is especially difficult in inner cities, where contractors have to deal with traffic, limited space, and restrictions with regard to emissions.

In order to deal with the changing circumstances and optimize the logistics, the parties need integral insight into the logistics of the project. There is a need for proper alignment between production, construction and transport. The aim is to have as little as possible slack throughout the construction process. This requires collaboration among the contractors and their suppliers. Furthermore, optimizing logistics means that the logistics of multiple construction sites need to be taken into account, as each project can be a hindrance to another. One respondent, one project can be a hindrance to another, and many construction parties are involved in multiple projects. The 4C therefore needs make sure that these hindrances can be avoided and allocate the available resources and capacities among the projects appropriately.

4.2.2 Product

There is a need for better information exchange among the supply chain parties, but how a 4C control tower would support this is not clear. There are different opinions on whether a 4C control tower is needed and in what form it could operate.

Multiple experts compare the 4C control tower for construction logistics to an air traffic control tower. Similar to an air traffic control tower controlling the arrival and departure of aircrafts at different runways of an airport, a control tower for construction logistics is a permanent entity that controls the deliveries for different construction sites in a certain area. To do this, the 4C is dependent on the data provided of the construction and logistics process of the various construction sites.

In order to help the clients, the correct information should be provided to the parties to ensure that any hindrance within that area can be avoided and the transport is correctly aligned with the construction schedule. The data gained from the supply chain can feed the different control tower functions. Based on the interviews, the following functionalities can be identified:

- *The monitoring of the construction and logistics process*
  Due to the constant changing circumstances affecting the construction projects, it is important that a control tower is able to provide the clients with real-time and accurate data of the construction and logistics process.
- *The alignment of transportation with the construction schedule*

The 4C monitors the construction process on the construction site and translates this to an optimized plan for transport and production for the suppliers and logistics providers. This includes information about when trucks have to leave to which construction site, what goods can be consolidated, and what routes trucks should take in order to arrive at the construction site according to the construction schedule.

- *The provisioning of insights into consolidation opportunities*

  The 4C should be able to provide the relevant contractors and suppliers with information about the consolidation opportunities to increase the load factor and reduce the kilometers driven.

- *The simulation of future construction transport based on project planning*

  The control tower should be able to simulate the construction transport in an area based on the project planning. This allows the local government and the contractors to take certain precautions, such as the signaling of traffic and the use of traffic controllers, to avoid congestion and other hindrances.

4.2.3 Customer interface

Although the 4C can be used by a wide variety of customers, it may not be able to provide sufficient value for all types of construction projects. Based on the interviews, a distinction needs to be made between the infrastructure projects and building projects.

Insight and control over the logistics is regarded as much more difficult in building construction than in infrastructure construction. In building construction, a large range of different parties is involved in the construction and logistics process. Each party is responsible for delivering certain work and may outsource some activities to other parties. In many cases, subcontractors and suppliers determine how transport is delivered and sometimes may use their own trucks. Consequently, the building site is a coming and going of various parties that are often temporarily involved in the project. Getting control and insight in the logistics is therefore regarded as an enormous challenge by many experts. This complexity makes coordination of logistics essential, especially among multiple neighboring construction projects area in a city.

Infrastructure construction on the other hand, is regarded as far less complex. This is an area of construction that is more developed with regard to how logistics is coordinated, because there often are fewer parties involved and communication is often more direct among the parties. The logistics flows are less sophisticated with many goods being delivered directly to the construction site. Goods often involve raw materials, such as asphalt or concrete, that cannot be consolidated and have to be delivered at the right time. Although control over these logistics flows is important, it is seen by the experts as less of a challenge than building construction. This makes the need for inter-project collaboration, and thus a 4C control tower, less needed than in building construction

4.2.4 Infrastructure management

The main component of the 4C infrastructure is the ICT. Various information architectures are possible to exchange data among the participating parties. The 4C control tower is a centralized information and control system that links the ICT systems of various supply chain parties and other external systems to provide end-to-end insight in the supply chain and improve chain-wide decision-making.

Communication

The experts have mixed opinions with regard to the need and the design of a viable 4C control tower as an inter-organizational ICT system. An important aspect of the 4C control tower mentioned is the interface through which multiple systems can communicate. Van Merriënboer proposes an open integrated system that everyone can use. Most experts argue in favor of a data-driven platform construction logistics control tower that provides the involved parties with real-time information about the construction and transport of a project. What data is available by the different parties and how it can be exchanged is unknown to the experts and requires further research.

In many cases, one can argue whether there is sufficient need to use ICT for certain communication. A recurring criticism of experts is that there tends to be too much focus on technology for improving construction logistics. Instead, focus should be placed on the concrete needs of stakeholders. As one expert mentions, site managers need practical solutions that are not too complex. In many cases, informal communication among collaborating partners, for example by phone, is sufficient to share insights. One expert even thinks that the most likely control tower will look like a conference call between the various partners.

BIM for logistics

One respondent argues that the control tower should be able to use the BIM planning to extract the various material flows. The insight in these flows can be used for further optimization by linking it to current stock level data and transport planning data. By using the right algorithms, the project data should be able to be used for estimating the number of deliveries, the amount of emissions and best transport routes to the construction site. However, the use of 4D BIM throughout the construction industry is limited. The appropriate ICT tools are needed to link the BIM planning with the logistics.

4.2.5 Financial aspects

The finance component has been difficult to assess by the experts. There is much uncertainty about the 4C control tower concept for construction. Not only are the experts not sure about the role of the control tower and what benefits it ultimately offers to the clients, but also about the actor that operates the 4C. Frazer and Van Merriënboer see the 4C control tower as an extension to the CCC and would therefore have a similar revenue and cost structure. However, Ploos van Amstel argues that the 4C should not be a for-profit entity to ensure its independence among the clients. A point of agreement among the experts is importance that the costs and benefits of the information exchange are shared fairly among the participants.

4.3 Obstacles

The organizational and technical obstacles of the 4C control tower is discussed with the experts. These obstacles may inhibit the implementation or use of a 4C control tower and would need to be tackled in order for a 4C control tower to be viable in the future. The most important obstacles mentioned are:

- No clear governance model
- No clear business case
- No proper chain-wide ICT usage
- Lack of data standardization
- Risks of data sharing

4.3.1 Governance model

An important question is who will play the role of a 4C control tower for multiple construction sites. The governance of 4C control tower has been a great debate among experts. The idea behind a centralized model is that chain control becomes more transparent and provides more opportunities for optimization. Experts agree that although the concept of a central entity to manage or support the management of the various supply chains sounds good in theory, it is difficult to implement in practice.

Some experts are critical of a centralized solution as it would impose more risk upon the participating firms with regard to organizational autonomy and vulnerability. Voordijk points out that project leaders are often “king of the project” and like to control everything that happens. A 4C can be regarded as an infringement on their autonomy. Others have also mentioned the risk of losing autonomy in the highly competitive construction industry. Ploos van Amstel argues that the competitiveness of individual firms may be affected if more information is shared between organizations and processed by the 4C and may require parties to change their role in the construction supply chain in order to stay relevant.

A centralized solution has been criticized for its insights and decision-making potential. Experts have argued that it would be impossible for a 4C to adequately take the interests of all individual organizations into account and create a "one-size-fits-all" solution for all logistical problems across projects. Parties do not want to become dependent on one party for information and insight. More extensive research is needed into the level of control the control tower is able to exercise.

Instead of centralizing information and control, some experts have argued for governance model that allows for decentralized information and control. Instead of limiting the freedom of choice and allowing one party to provide the specific insights, the participating parties provide the data among each other and make the best possible decision for themselves. This also allows for competition in the way optimizations are made. A decentralized solution would require a protocol that allows the ICT systems of all parties involved in the construction projects to communicate and share relevant data with each other so that a central orchestrator is not needed.

Types of control towers

The 4C control tower could be described from multiple perspectives. Each party in the supply chain has a certain level of insight and control over the logistics multiple construction projects. Based on the interviews, two types of these control towers can be distinguished

<u>Construction consolidation center</u>

Many experts see the need for a 4C control tower from the viewpoint of a CCC. The CCC is an independent logistics provider or a supplier that provides additional logistical services. The CCC is by some experts seen as the center in a city from which multiple logistics flows can be coordinated and optimized. According to Frazer, contractors do not have the insight of the logistics flows of other construction projects to be able to properly optimize their logistics. A CCC on the other hand, is the party above the projects and is able to provide them the 4C functionalities, such as the planning of transport and the bundling of goods across projects. In addition, the CCC may have established multiple long-term collaborations with suppliers which allows for easier coordination.

However, opinions vary greatly in the extent to which the CCC is able to fulfill the 4C role. One expert claims that the CCC is too often seen as the "holy grail" in construction logistics but is only part of the solution to the logistics problem. In practice, the CCC can take different forms and its effectiveness is greatly dependent on its geographical location and its logistical capabilities. Changing the mode of mode of transportation, such as from road to water, or the consolidation of goods is not always a solution for certain goods.

Based on the interviews, three reasons can be distinguished why the CCC is not the suitable actor to fulfil its role as a 4C control tower.

- The CCC is not able to oversee all logistics flows in a certain area. The CCC is often only used to a limited extent by the contractors. Certain goods are not suitable for temporary storage or consolidation and full truck load deliveries should be delivered directly to the construction site at a just-in-time basis as much as possible, instead of stopping at the consolidation center. Optimizing logistics means that these deliveries should be delivered directly without any problems.
- The CCC is only able to control the logistics flow to a limited extent. The consolidation center does not coordinate the goods in so far that it determines what is being delivered to the various construction sites. The contractor is the actor that determines what goods are delivered to the construction site based on the building schedule and communicates this with the CCC. The main responsibility of the CCC is to deliver to goods to the construction sites in time upon call-off from the contractors.
- Opinions also differ on the extent ICT integration is needed between the CCC and its partners to coordinate the logistics. Although the lack of ICT integration with the CCC is mentioned by various experts, the extent this is ultimately be needed remains unclear. One critical expert argues that the CCC does not need sophisticated ICT systems in order to properly operate. It is often easier for contractors and suppliers to directly contact the CCC over the phone and ask for certain goods to be delivered.

Local government

There are also experts that view the local government as the party to operate the 4C control tower.

There is a strong need for the local government to ensure that the contractors take the livability of the city into account in their logistics process. Some experts argue that the coordination of multiple construction projects to improve the logistics is not something the market will do itself due to a lack of incentive. The willingness and capability (funds) to invest in logistics optimization is often lacking. Time and budget constraints often do not provide much room for contractors to innovate and experiment. To improve this, contractors should select partners based on their logistical capabilities rather than on their price.

The local government is considered an important stakeholder and can play an important role in logistics coordination. In order for contractors to obtain a permit, contractors need to develop a logistics plan detailing how they plan to the supply logistics. According to Walinga, the local government could require all transports to be registered, and in return provide certain benefits, such as allowing them to use the bus lane or providing a "green wave" at intersections By requiring contractors and their partners to meet certain logistical criteria, including the use of a 4C control tower, the local government can incentivize construction parties to better control their logistics and make the necessary investments.

The local government would use the control tower to monitor the logistics process of the projects, verify whether the number of transports corresponds with contractor's logistics plan, and simulate future road usage based on traffic data and the construction schedule. This may help the local government in ensuring transport agreements with the contractors are met and in deciding whether to take certain traffic measures that reduce the hindrances in the city.

However, there are several points of criticisms put forward by the experts.

- There are questions regarding the role of the local government in the optimization of the logistics process, as an independent actor outside the construction supply chain. One respondent is critical of the local government and its ability to make the right decisions to control traffic. From his past experience with local governments, there would need to be clear how the local government is able to help the logistics process.
- Another expert sees no need for a local government to require construction companies to improve construction logistics, since the they are often willing to do this themselves. Contractors are becoming more aware of the benefits of new logistical concepts, such as the CCC, and the need for better logistics management in inner cities.

4.3.2 Business case

There is a lack of insight in the concrete benefits, costs and risks with regard to the use of a 4C control tower. A clear business case is needed before potential clients are willing to collaborate and participate in the 4C. A business case describes the reasoning for undertaking a particular action or project.

The 4C control tower is dependent on the data of its clients. Therefore, clients will need to make the necessary investments in IT and training. The experts have mixed opinions regarding the added-value of a 4C control for the stakeholders. One expert points out that introducing new logistical concepts and technologies with partners has often been unsuccessful due to the low return on investment. Unless there is enough incentive, people will stick to their traditional way of working.

Supply chain visibility is regarded as a great benefit by some experts. One expert points out that contractors may use it to search for alternative suppliers if their current supplier is unable to deliver certain goods. Although transparency may help the contractor in finding appropriate alternative suppliers, the question in how far this is better than their traditional way of working. According to another expert, contractors will "simply" find alternative supplier in the area and contact them themselves by phone.

It is questionable whether the control tower is able to provide sufficient value for its clients to make the investments required by all involved parties worthwhile. Two main reasons can be distinguished that make it difficult for the involved parties to develop a concrete business case.

- The unique and one-off nature of construction makes it difficult to determine the costs and benefits of using a 4C control tower. Although the 4C could require all parties in a project to make certain investments in order to share data, it is questionable whether those parties will ultimately benefit from the investments in the projects they will conduct in the future. The configuration, capabilities and needs of the supply chains are different for every construction project. It is difficult to determine for each project at what point the tracking of deliveries and the planning of consolidation through a 4C is needed. Even if a business case can be made for a project, there is no guarantee that the estimated reductions in costs and emissions can achieved due to the constant changing factors that affect the construction and the logistics process.
- In addition, contractors have insufficient insight into the current costs and emissions of the logistics. This makes it difficult to estimate and evaluate the effect the use of a 4C

control tower has on the logistics management and what improvements are needed as compared to the traditional way of working to make its use viable. The lack of insight into the current logistics costs can be attributed to the fact that it is not insufficiently measured and shared among parties. Logistics is often provided as an additional service of which the costs are included in the contract price.

4.3.3 ICT usage

A 4C control tower is dependent on the data from its clients in order to obtain end-to-end visibility of the supply chain. Data originating from the supply chain needs to be communicated in an accurate, reliable, complete and timely manner. However, there are experts highly doubt whether this can be guaranteed by all participating parties. The construction supply chain consists of a wide variety of parties that each have their own level of ICT maturity. Although many construction parties see ICT as important to conduct their business, they are only willing to invest in it insofar that it is needed. Many experts have addressed the lack of proper ICT use as an obstacle for supporting an inter-organizational data platform.

- The potential of BIM is often not fully exploited in practice. 4D BIM allows parties to see the how building product is to be constructed over time. However, the planning is often made and updated separately from BIM on a different application, and sometimes not even digitally. Van Merriënboer points out that some construction projects print out their planning and hang it on a wall once the construction becomes operational. Furthermore, although there have been advances in technology to capture and compare the current state of the construction with BIM (e.g., through sensor technologies), the updating the construction planning is still dependent on manual input.
- The parties lack the tools to properly use the BIM planning for their logistics. Even if the 4D BIM is properly used by the participating parties, there is a gap between the BIM planning and the transport of the components. The specifications of the components in BIM according to the contractor often do not align with the delivery specifications of the supplier or carrier. For example, the BIM planning may say what tiles need to be constructed on a specific date, but it does not say how it is packaged and delivered by the supplier. Furthermore, contractors currently lack and could be used, through the use of the proper scripts, to extract data that can be used in the logistics process (e.g., what goods are suitable for consolidation).

4.3.4 Risks of data sharing

In order for a 4C to provide its services, the participating parties are required share their data with the control tower. This could include data about the construction planning, delivery planning, stock levels and transport details. Despite the need for communication and transparency, experts see the potential risks that may deter parties from using a 4C control tower.

The lack of willingness to share data has been mentioned to be inherent to the culture of the construction industry. Parties involved in the construction rather keep the data to themselves to allow certain leeway during the project. By withholding data, parties ensure that their data cannot be used against them or that it is used solely for the benefit of others. Many parties benefit from the so-called "smokescreen" that covers up the real costs of their operations from others. One expert says that parties that benefit from the lack of transparency and are at risk of becoming redundant will try to stop the development of a control tower. Furthermore, it is difficult for parties assess the value and sensitivity of certain data. The participating parties will therefore be hesitant to share data unless returning benefits can be ensured.

In the development of an 4C control tower, or any type of inter-organizational system, the risks associated with data sharing has been an important factor. A few important questions asked by one respondent is: who determines what data is provided, how can you ensure that the data is provided, and does there need to be a distinction between "needs to have" and "nice to have" data. In resolving these issues, it requires parties to come to an agreement about what data is shared.

4.3.5 Data standardization

A number of experts has mentioned the lack of data standardization as an important obstacle for the realization of a 4C control tower. Interoperability is important to allow for efficient and effective information exchange. The quick-connect and disconnect is an important requirement of the 4C control tower to allow for agile business networks. According to Van Merriënboer, it is difficult to integrate all ICT systems and centralize all data due to the wide variety of systems used by the different parties. He suggests that a new standard or protocol is needed to communicate construction logistics between the various partners.

Several experts regard the standardization of information between projects as extremely difficult to even impossible. According to Voordijk, standardization is difficult due to the enormous diversity of projects. The information exchange does not only differ from project to project, but also between the different phases of one particular project. The use of unique and one-off products also adds to the difficulty of standardization.

There are several different product and communication standards in construction and installation sector, such as ETIM (i.e. a standard for classification for product details), SALES (i.e. a standard for electronic communication) and GS1 (i.e. a standard for the identification of product and address details). IFC, is the communication standard for BIM among the construction parties. Their downside is that their use differs throughout the construction supply chain.

5. Implications

In this chapter, the literature on construction supply chain management and the 4C concept are confronted with the results of the interviews to discuss the implications for the construction industry.

5.1 Implications for construction industry

In this section, the implications of the proposed 4C with regard to the IT across the construction supply chains are discussed.

The proposed 4C solution as is described in the business model is an independent business entity that supports collaboration across construction projects through a centralized inter-organizational data platform. An at-scale 4C control tower for multi-project collaborations allows for greater optimization opportunities, such as the sharing of resources and logistics capabilities (De Bes, 2018). However, the experts are critical about the possibility of one focal actor for cross-project collaboration.

Decentralized information and control

Instead of one focal actor functioning as an information hub, a decentralized form of governance for information and control, i.e. participant-governed network (Provan & Kenis, 2008). This form of governance has been mentioned by several experts, including Van Merriënboer and Ploos van Amstel. The construction supply chain could consist of multiple open systems that each can provide insight into certain parts of the logistics chain. Communication with among those systems that are involved in your supply chain will enable you to get an integral view of the logistics. This would entail that each party, CCC, the local government, contractors and suppliers, would operate as their own control tower.

Alternatively, one could look to new technologies to enable decentral control over information in a network, for example through the use of blockchain. Blockchain would theoretically allow for the disintermediation of a focal actor that manages data transactions in a network (Mattila, 2016). However, this technology is still very immature and still has to prove itself in practice (Carson, Romanelli, Walsh, & Zhumaev, 2018; Higginson, Nadeau, & Rajgopal, 2019). Several things need to be taken into account when applying this technology. Assuming the blockchain is public, the involved parties would need to be able and willing to use cryptocurrencies for every transaction that they perform through the blockchain network. In order for a blockchain to be decentralized, cryptocurrencies are essential as they function as incentive for miners (i.e.

the nodes that create new blocks with transactions) (Drescher, 2017; Narayanan, Bonneau, Felten, Miller, & Goldfeder, 2016). There are also several challenges regarding their scalability, security, lack of flexibility and lack of privacy (Drescher, 2017; Swan, 2015; Zheng, Xie, Dai, Chen, & Wang, 2018).

Need for industry-wide protocol

Regardless with whom parties communicate (i.e. with the 4C or among the parties themselves), a control tower is dependent on the data provided by others in the supply chain in order to gain insight in the integral logistics and provide optimization. The data needs to be reliable, accurate, timely, and useful for others (Zhou & Benton Jr, 2007). The IT landscape of the construction supply chains consists of a wide variety of systems that do not communicate (O'Brien e.a., 2008). Various experts acknowledge that the IT systems currently in use are mainly focused on internal operations rather than the information exchange with other parties in the supply chain.

To enable the data exchange, a protocol for data provisioning is needed that each party involved in the logistics of a construction project complies to. This protocol should define what, when and how data is exchanged. Due to the characteristics of construction supply chains, such as their temporary and changing configurations across projects, this protocol would need to be able to be implemented industry-wide.

Open standards are crucial to enable interoperability across the IT systems in an inter-organizational setting. These open standards do not only allow parties to come to a shared meaning of data (i.e. semantic interoperability). This includes details about the warehouse (e.g. available space, products in stock) and current and planned deliveries (e.g. estimated time of arrival, truck load factor and planned route). For this, the industry has to look to existing open standards and possible new standards. Furthermore, the quality of the open standards needs to be guaranteed (E. Folmer, Luttighuis, & van Hillegersberg, 2011). Due to the lack of standardization on both the product and the production level, this is will be difficult to achieve.

Control tower solutions

Assuming the parties are willing or are required to share their data with others, control tower solutions are needed to monitor and process the information that is shared. These control tower solutions could be targeted to contractors and suppliers, for the monitoring of the logistics process and the planning of consolidation, and to the local governments, to monitor the transports of construction projects in a particular area. An example of a control tower solution is described in subsection 1.5.2.

5.2 Implications for VanMeijel Automatisering

VanMeijel Automatisering B.V is an IT provider for companies involved in civil engineering, construction and industrial services. The company is based in Emmeloord, The Netherlands, with subsidiaries in Eindhoven and Amsterdam. Its primary product, the Metacom Platform, is an integrated business solution that provides small and large companies with the ability to support the logistics and service processes, including the associated administrative handling.

The Metacom Platform

The Metacom Platform consists of two products: Metacom+ and Metacom Online. The distinction is illustrated in Figure 23.

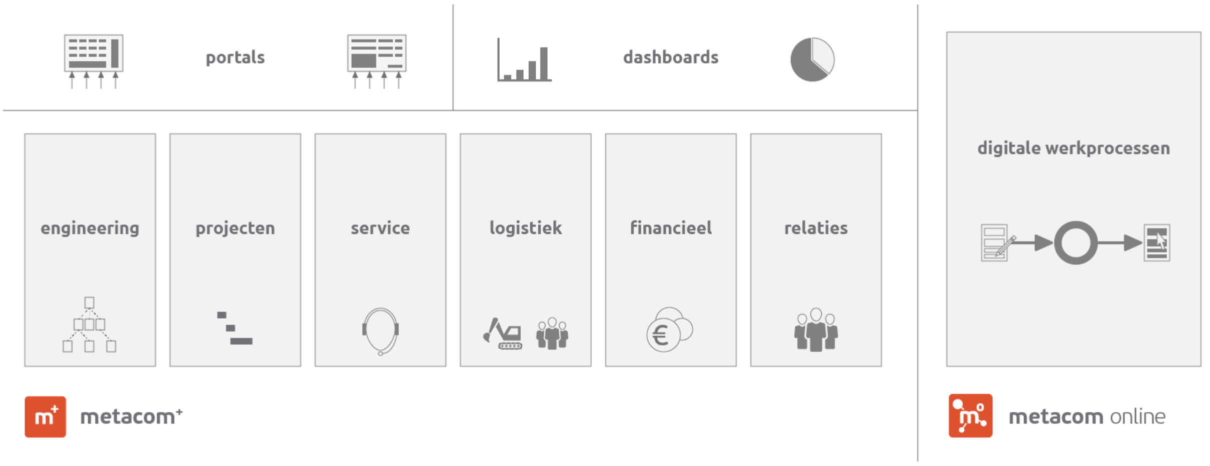

Figure 23 - Metacom platform (copied from VanMeijel)

<u>Metacom+</u>

Metacom basis is the construction ERP offered to companies involved in construction projects. Metacom+ is extends this with Metacom Projecten and the dashboard functionalities. Metacom a central hub for enterprise and project administration integrated with the financial and logistical processes. Metacom allows businesses to digitize their processes, including calculation, procurement, invoicing, quality registration, planning, daily reporting, sales, production registration, equipment rental, work orders. For example, the 3D-model, BIM, can be used for cost calculation planning and project control. Metacom+ also provides BI and dashboard functionalities gain insight into certain performance indicators, reports, and trends.

Metacom Online

Metacom+ functionalities can be extended with Metacom Online. Metacom Online is a cloud-based platform for supporting digital processes, such as hour registration and procurement processes. The platform is available for every device to allow users to gain access to the relevant information from anywhere. Furthermore, the functionalities can be extended with external devices and applications through its open API infrastructure.

As not every company in construction is the same, the Metacom is a flexible platform that can be adjusted to the needs of the customer. The Metacom Online platform consists of various packages. A package is a bundle functionalities that can be offered on top of the Metacom Online platform depending on the need of the customer. The following packages are offered:

Package	Description
Inkoop factuur afhandeling	For digitizing the approval process of invoices. The invoice is received in Metacom and send to Online for approval and payment.
Afval Container Transport	For everything surrounding waste management, recycling and (container) transport
Externe bonnen	For creating external tickets for suppliers, for example blanket orders.
Bouwplaats	(For contractors) For showing daily and weekly reporting of the construction site.
Productieopgave	Registration of the costs and revenue of production.
Order tot werkopdracht process	For converting purchase orders into work orders. Mainly focused on service-oriented businesses. Does not require ERP Metacom.
Urenregistratie	For weekly time registration. Mainly used by office staff.
Werkopdrachten	For registration of work orders. This package is integrated with the equipment planning in Metacom.

Table 4 - Metacom Online packages

In the project Metacom 2020, VanMeijel plans to move all Metacom+ functionalities to the Metacom Online and to make it accessible via the web browser. This also entails that the customers of VanMeijel will slowly move to the cloud-based platform and benefit from the connectivity and accessibility of the information on the platform.

Implications product portfolio

At the moment, Metacom is mainly focused on the internal logistics and project administration of its customers rather than that of the supply chain as a whole. We have found that the exchange of logistics data among parties faces several issues, including the vulnerability risks and data standardization. There is an increasing need from both the local governments as well as the main contractors to better organize logistics. Both the local government and the contractors need better insight in the supply of the projects. The local government may require contractor to only select suppliers that are able to meet certain logistical capability requirements. The necessary IT should be provided that allows those parties to meet those logistical requirements and share the necessary insights. There are several potential product solutions that VanMeijel can implement to optimally leverage the logistics optimization opportunities. This is illustrated in Figure 24.

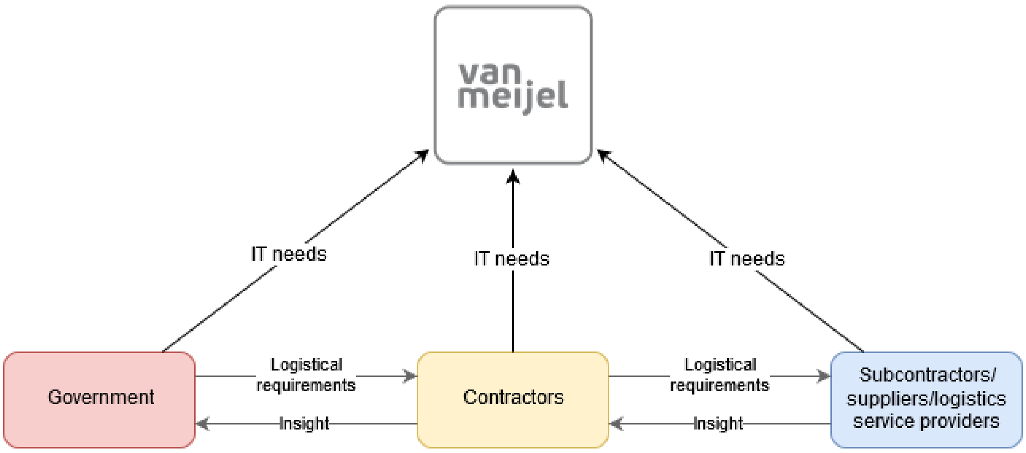

Figure 24 - Market IT needs

Instead of focusing on the information exchange with a central actor (the 4C), Metacom could operate as a control tower to allow its clients to better organize logistics among themselves. VanMeijel could fulfill the needs by allowing its users to monitor, process and share logistical information. An additional package could be offered that focuses on integral logistics visibility and control. Examples of such solutions are the supply logistics dashboard and the Consolidation planning tool.

Supply logistics dashboard

Potential users: contractors, CCCs (suppliers, LSPs), and local governments

There is both a need from the construction companies to have better insight and control over the logistics of a construction project. The contractors will want to know from its partners what materials have been ordered and at what time they will arrive at the site in order to align the unloading with the on-site logistics (e.g. the crane planning). Through information exchange with its partners, the supply logistics dashboard does not only provide insight into the company's own transport, but also that of its subcontractors and suppliers.

For the data exchange, the sector could use the OpenTripModel (OTM). The data could include various details, including vehicle details, transported goods, load factor, kilometers driven, current location, planned route details, etc. Insight into the current and planned deliveries from suppliers does not only allow contractor to better organize the supply with the on-site logistics, it also allows them to monitor the performance of the overall project. This can be used by the contractor to assess the project's performance for future reference and to see if certain requirements set by the client of local government are met. This solution is dependent on the data that is shared by all parties participating in a project to have an integral performance overview of the project. This would therefore be most suitable for contractors that require their partners to share this information.

This dashboard does not only need to be used be construction companies, a new market segment VanMeijel could focus on with this package are local governments. The local government currently has no insight in how goods are transported and whether the construction companies comply to the governments' requirements to reduce the number of deliveries in the city. Local government are demanding more from contractors with regard to how they organize the logistics. In order to make sure congestion, emissions, and noise in the city, they need insight into all deliveries of the construction projects in that area.

Similar to the contractors for a particular project, local governments could use the logistics dashboard of VanMeijel's new package to oversee all transport in a certain area. This would require contractors and their suppliers to register all their transport in that area with the local government. In order to enforce this rule, cameras can be placed that monitor the deliveries. Consequently, local governments could use this data to simulate city traffic and take appropriate traffic measures, including opening up bus lanes for trucks and the use of traffic signs and controllers.

The supply logistics dashboard can be used to monitor different KPIs, including:

KPI	Route/locations
On time deliveries	supplier – CCC, supplier – construction site
Deliveries in accordance with the requirements	supplier – CCC, supplier – construction site
Waiting time	Construction site, CCC
Unloading time	CCC, construction site
Emissions (CO2, NOx, PM10)	supplier – CCC, supplier – construction site
Number of kilometers driven	CCC - construction site
Number of avoided kilo-meters	supplier – CCC, supplier – construction site
Cost savings	supplier – CCC, supplier, supplier - construction site

Table 5 - Dashboard KPIs

<u>Consolidation planning tool</u>

Potential users: contractors, CCCs (suppliers, independent LSPs)

Insight in the transport and orders of a project may reveal new opportunities for optimization. One way to optimize the supply logistics for a particular construction project is the consolidation of goods from multiple suppliers for a single last-mile delivery. This reduces the number the number of kilometers driven, the amount of emissions to the construction site and costs. The consolidation of goods also allows for just-in-time delivery which makes the delivery of goods to the site more reliable. Construction Consolidation Centers are becoming more well known among contractors and suppliers that operate in inner cities.

A solution is needed that allows contractors to better plan the use of the CCC. The package could include a tool for construction companies to organize the consolidation of goods. In order to do this, contractors could use the data derived from 4D-BIM. Based on the types/size of material and time of assembly on site, contractors could determine what material is suitable for consolidation. If this is the case, the contractor could notify involved suppliers to deliver the goods at the consolidation center and the consolidation center about the opportunity to bundle the goods in one freight. In addition, the extracted data from BIM could be used to detect clashes with the on-site logistics. For example, this can be used to see whether certain consolidated goods can fit on the elevator.

Although the consolidation planning for specific project is mainly focused on contractors, VanMeijel could also target suppliers and logistics service providers. The new Metacom package could be focused on CCCs, suppliers and other logistics providers to find inter-project consolidation opportunities. This allows other parties than the CCCs to provide consolidation services.

This allows CCC to operate similarly to UberPool, but for goods of different construction sites. Using this tool, the CCC, supplier or other logistics providers are able to match certain goods with other goods that are heading in the same direction. If multiple contractors require deliveries to neighboring construction sites, the CCC should be able to find opportunities for consolidation based on the product details and the location of the construction sites. These details can be derived from individual project planning shared by the contractors (4D-BIM) or could be registered as the goods arrive at the CCC. The latter is the most likely as the products may be packaged in a way that affects the consolidation. If the multiple products are able to share truck capacity, the consolidation center can notify the involved contractors about this opportunity. Planning the consolidation for multiple projects will always have to be done in coordination with the involved contractors. If two contractors need their products on two separate days, the CCC could ask one of the contractors if it is possible to deliver their product a different date.

6. Conclusion

6.1 Answer to the research questions

In this section, the research questions as posed in section 1.4 are addressed.

RQ1: What is construction supply chain management?

A supply chain is a network of organizations that are involved in the flow of information and goods up and downstream, from raw materials to the distribution of the final product to the user. SCM is the strategic and systematic coordination of certain business functions for the benefit of the individual company and others in the supply chain.

The construction supply chain is a complex network of parties that exchange goods, information, and money related to the completion of a particular construction project. This includes the clients, engineers, general contractors, manufacturers and suppliers, users and the government. The construction supply chains are characterized by their complexity and fragmentation. There are many specialized parties involved that are responsible for executing part of the construction work. The supply chains are focused on the convergence of materials to one particular site where it is assembled into the final product. This often occurs on a make-to-order basis where new temporary coalitions of parties are formed.

The complexity of construction supply chains makes the management of the logistics a difficult task. Goods are typically ordered by the contractors based on the project planning and delivered directly to the construction site. In recent years, construction consolidation centers (CCC) have been established and have helped contractors to better manage the logistics of their construction project. Through the use of a CCC, goods can be temporarily stored off-site and delivered on just-in-time basis at the construction site. In addition, instead of multiple trucks arriving at the construction site with low load factors, the CCC can be used to consolidate the goods into one truck. This reduces both costs and hindrances to the environment (e.g. congestion, noise, pollution).

RQ2: What is a cross chain control center?

A Cross-Chain Control Center (4C) is a control center from which multiple supply chains can be coordinated. It has been described as both a consultancy company as well as an IT company through its use of advanced technologies and supply chain professionals. By coordination the flow of physical goods, money and information of multiple supply chains from a central platform, it aims to provide efficiency advantages to all supply chain partners. The 4C can be used to manage transportation, finances, procurement, and warehousing activities across the supply chain.

Horizontal collaboration is more difficult to achieve than vertical collaboration due to the lack of trust among competitors. In addition, it is more difficult come to a fair allocation of benefits and costs. Different governance models for an inter-organizational system can be used, including a participating-governed network, a lead organization, network administrative organization.

RQ3: What would a 4C for construction look like?

This question is answered through a business model design. The idea behind the 4C is that it supports multiple suppliers to collaborate and share their capacities. The business model is developed based on the vision as described in the end report of the TKI-project "4C in de bouwlogistiek" and the current literature on the 4C concept and construction supply chain management. The functionalities, such as the planning and monitoring of transport, are addressed.

This business model addresses four major components, including offering, customers, infrastructure and finances. These form the internal foundation of the 4C control tower. A business model canvas is made to illustrate the 4C concept.

- **Customer interface**
  The clients of the 4C includes all major stakeholders that are involved in the logistics process, including the general contractor, the subcontractors, suppliers, carriers, and government. The 4C control tower should be able to address their needs with regard s to the transportation of goods within and across the supply chains.
  The 4C should allow for instant and seamless service provisioning and communication between the 4C and its clients. Communication can be established using custom web APIs to integrate the legacy systems of the control tower. In addition, it is important for a 4C to continuously seek for new opportunities and ensure that the benefits and costs are shared fairly. And lastly, serious games can be used to raise awareness and induce a mental shift about collaboration opportunities among clients.
- **Product**
  The 4C control tower seeks to provide value to the whole business network through improved supply chain performance. This can be enabled by offering services that

facilitate and foster collaborations, enable safe data exchange, and exploit supply chain synergies. By monitoring the supply chain activities, such as the transport of goods, the 4C could look for opportunities for consolidation among suppliers.

- **Infrastructure management**
  The infrastructure of the 4C describe the key activities, key resources, and key partners. The key activities of the 4C include all activities with regard to network coordination, alliance management, and administration. Its main resources are the ICT-infrastructure, which allows the control tower to receive, process and send data to support its network coordination activities, and the personnel, which are needed to perform alliance management processes and use and maintain the ICT. There is a range of possible partners that may help provide value for the clients: hardware/software providers, advisory/consultancy firms, and research institutes.
- **Financial aspects**
  There are different ways for the operator of the 4C to monetize the its services. This can be done on a per transaction basis or via a periodic fee. The cost structure of the 4C typically consists of the investments in human resources and the underlying IT infrastructure to support the coordination processes (e.g. monitoring, planning, simulation, etc.). In addition, there may be costs associated to the formation of alliances and the marketing activities.

RQ4: To what extent does the designed 4C fulfill the needs of the supply chain actors?

Interviews where held with industry experts to further explore the possibilities of a 4C control tower for construction. The findings indicate that although there is a need for better logistics control over the supply chains, especially in inner cities, the experts have mixed opinions on whether a 4C control tower is able to support this. The essential functionalities of the control tower would include the monitoring of the construction and logistics process, the alignment of transportation with the construction schedule, the provisioning of insights into consolidation opportunities, and simulation of future construction transport based on project planning. This control tower is most likely needed in building projects rather than infrastructure projects, due to characteristics of the logistics flows. The logistics flows of building construction are more of a challenge to control and provide opportunities to consolidate.

Although the proposed 4C control tower would be ideal for managing the supply chain, there are various organizational and technical obstacles that need to be overcome before a potential 4C control can be implemented. First of all, there is no clear governance model. Integral insight and control into the logistics of multiple projects is needed, but a centralizing this into one control tower is highly unlikely, according to the experts. There is a risk of losing autonomy and becoming too dependent on one solution. A CCC and the local government have also been mentioned as potential parties to operate the control tower. Others argue for a more decentralized solution where different parties have certain responsibility with regard to the logistics process and that communication should be the main focus. In addition, there is a lack of a clear business case from using the 4C control tower. It is difficult to assess the potential benefits and whether this makes the investment in the solution worthwhile. Furthermore, the control tower is dependent on the data from its clients, but current ICT use throughout the construction supply chain is insufficient. This can be attributed to a lack of incentive to invest and use the ICT, and the lack of the proper tools that allow parties to communicate and use the data from a control tower. The standardization of information among supply chain parties would also make it impossible to use an inter-organizational data platform, such as a 4C.

RQ5: What are the IT implications of the designed 4C control tower in general, and for VanMeijel in particular?

The findings that there is a lack of communication across the supply chains to support effective logistics management. While the literature suggests that coordination through inter-organizational information integration can improve insight in the logistics and the decision-making of supply chains, the potential role and organization of a 4C control tower for the construction industry is not explored. Based on the findings, it seems that a decentralized form of governance for information and control is the most appropriate for the construction industry. This would require a protocol that allows parties to share the relevant data about their logistics among each other. Each party that they would need the necessary tools that support this. For construction companies, they would need to be able to extract the possible deliveries from the planning data and use it to coordinate the logistics providers. Contractors and their suppliers should be able to share real-time delivery data. =Local government would like to have insight in all transports in a certain area and future transport based on the construction planning. The logistics provider and contractors should therefore be able to share their (planned) transport data with the local government. Consequently, the local government would need the proper IT to be able to analyze the data. From these IT needs, the implications for VanMeijel Automastisering have been derived.

6.2 Reflection

Looking back, we have several points of criticisms about the concepts and methods that have affected this research.

Business model design

First of all, the choice to use the Business Model Canvas (BMC) as developed by Osterwalder, Pigneur, & Tucci (2010). This framework was to describe the business logic of the 4C model, but there are several limitations for its use in this specific case. The Business Model Canvas is mainly focused on the internal organization and does not take the external context into account. Logistics innovation requires collaboration between stakeholders and a reliable business model due to the varying interests of construction stakeholders (Barbosa e.a., 2017; Vries & Ludema, 2012) An attempt was made to come a more detailed model that takes networked organizations into account, such as the Value Information Process (VIP) framework by Solaimani & Bouwman (2012). Solaimani argues that an abstract business model should be designed, for example by using the BMC, that can then be translated into a more detailed business model that takes the external environment into account (i.e. business model implementation or business model execution). The VIP framework allows the designers to communicate the value, information and processes that are exchanged in the network. However, due to the lack of data derived from the interviewees and literature, we were unable to make a more detailed business model concept of the 4C control tower its role in the business network.

4C concept

There are many uncertainties that affect the decision as to what information should be exchanged among the parties and what level of control the 4C is able to exercise. Much of the uncertainty about the control tower for construction can be attributed to the lack of clarity of the 4C concept itself. The ambiguity surrounding the 4C term can be found both in literature and among experts. The 4C is by many experts considered to be a vague and all-encompassing term that can be used in many ways to define different solutions. Although the end-report TKI-report "4C in de Bouwlogistiek" (Merrienboer, S.A. van & Ludema, M., 2016) proposes the development of a 4C control tower for construction logistics, it lacks a definition of the 4C and the control tower concept.

A study by Gartner (Pradhan e.a., 2018) is critical of the control tower concept as it has often been used by software vendors to market different supply chain solutions. On a similar note, the use of the term has also been criticized several respondents. One respondent argues that the

4C control tower is somewhat of a hype term that is used by both practitioners and researchers in construction and logistics. It is considered "sexy" to claim to use a consolidation center, perform logistics management, or have a control tower. Two experts point out that they have not seen a true 4C in practice as of yet. There are many questions to ask about the future of the 4C concept and its application in practice, given the lack of examples of successful independent 4Cs.

6.3 Limitations and future research

This research investigated if and how a 4C control tower could be applied in the construction industry to support the supply chain management. This was done through a literature review of the concepts of construction supply chain management and the Cross Chain Control Center. A business model was developed to describe the workings of the 4C, following the vision of previous research of a 4C control tower for construction logistics. This idea was validated with a number of industry experts.

For the construction industry, the 4C would entail an inter-organizational data platform operated by an independent entity that supports collaborations across construction projects through integral information and control. Dutch research institute TNO proposed the development of a 4C control tower for construction logistics and has recently submitted a research proposal to do more extensive research on this topic. We have found significant obstacles that would hinder the development and implementation of such a platform. Instead of a centralized solution, one could look into the responsibilities of each party within the supply chain, their data requirements, the available data in the supply chain, and how that data can be obtained. The findings indicate that a decentralized form of governance with multiple open systems could be an alternative. Although this research has touched upon this slightly, future research can expand on this form of information and control.

There are several limitations of this study that need to be taken into account.

- The first limitation of this research is that fact that it is conducted by someone outside the construction and logistics sector. This could mean a bias towards the use of a certain business or IT solution where in practice this is not needed by the potential users. An attempt is made to limit the bias by being of aware of the fact that bias could affect the research and by using data from different sources. The technocentric bias of researchers in general has been a point of criticism by several respondents. Future research should focus on proper stakeholder analysis to ensure that the solution addresses the problems and needs of the users, while keeping the costs and risks into account.

- Secondly, the bias of the respondents needs to be taken into account. A selective group of experts is used to ensure the external validity of this research. This group includes both academics and industry professionals with each their own expertise. Due to the noticeable differences in responses on what a 4C is and how it could work, the bias of each expertise must be taken into account. The limited sample size of each expertise may affect the outcome of the study. As the 4C involves a large range of stakeholders throughout the construction industry, future research should involve a more diverse group of experts.
- Thirdly, describing the concept of the 4C control tower for construction logistics has been found a difficult task due to the large range of topics it covers, which in turn may limit the depth of the study. The concepts used in this thesis could fill up entire books. However, this study is only able to describe these elements in a limited number of pages. An attempt is made to offer researchers, including Dutch research institute TNO, a starting point to further investigate the 4C and the relevant adjacent concepts.

6.4 Research relevance

The contribution of this research can be divided into practical relevance an academic relevance.

6.4.1 Practical relevance

The practical relevance of this research lies in the assessment of a 4C control tower design that addresses the need for efficiency improvements in construction projects. The implementation of the 4C concept in practice has been followed with great interest by both practitioners and researchers this past decade. Dutch Topsector Logistiek has had great ambitions with regard to the 4C concept and set up goals to make the Netherlands international leader in logistics and supply chain orchestration.

In 2020, Dutch research institute TNO is expected to investigate the 4C concept in construction more extensively in a new research project. Although the details of this project are unknown to the author, this thesis may contribute be providing insight into the relevant concepts. This report lays out what the 4C concept is and some of the issues that need to be taken into account if an inter-organizational data platform where to be realized in the construction.

This thesis attempts to answer questions that concern the stakeholders of the construction industry regarding the functions of a 4C actor. This study ensures its practical relevance through close collaboration with VanMeijel Automatisering, an IT service provider that has over thirty years of experience operating in the construction industry. For VanMeijel Automatisering, research into a 4C control tower provides insight into the future of construction supply chain management and reveals new opportunities for their product portfolio. The last part of the thesis lays down the implications that a 4C design could have for the industry, and for VanMeijel Automatisering in particular.

6.4.2 Academic relevance

The 4C has been described as the next big step in supply chain management and promises to improve supply chain performance by, among other things, enabling data sharing among 4C clients and providing network coordination services (De Kok e.a., 2015; Topsector Logistiek, 2015). Limited research has been conducted and published on inter-organizational systems for supply chain coordination in general and for the management of the construction supply chains in particular. The concept of an actor to facilitate cross-chain collaborations is a very promising, but also a challenging one as it requires the chain-wide IT integration. The use of information systems in an inter-organizational context has been a topic of research since the 1980s, but there is a need for more diverse and cross-disciplinary studies (Robey e.a., 2008).

This research contributes to the existing knowledge base regarding issues and possibilities of construction supply chain optimization. This study contributes to this knowledge domain using the concept of 4C. While the potential creation and use of the 4C has been described in fast moving consumer goods (FMCG) supply chains, it has only been described as a vision for future construction logistics.

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Appendix A – Interview experts

The following industry have been interviewed:

Respondent	Organization	Background
Bas van Bree	Dinalog	Program Manager Cross Chain Control Centers at Dinalog
Arjen de Feijter	Dura Vermeer Infra Landelijke Projecten	Logistics manager at Dura Vermeer Infra Landelijk B.V. This subdivision of Dura Vermeer is responsible for large projects ranging from 10 to 100 million euro.
Ron Frazer	VolkerWessels Bouwmaterieel	General director at VolkerWessels Bouwmaterieel. This subsidiary of VolkerWessels is responsible for the Construction Consolidation Center in Utrecht.
Marcel Ludema	Delft University of Technology (TU Delft)	Assistant Professor at the Faculty of Technology, Policy, and Management of the TU Delft.
Siem van Merriënboer	TNO Mobility and Logistics	Logistics consultant at TNO in the Netherlands.
Walther Ploos van Amstel	Amsterdam University of Applied Sciences (HvA)	Lector City Logistics at the HvA
Hans Voordijk	University of Twente (UT)	Associate Professor at the Department of Construction Management and Engineering of the UT.
Ruben Vrijhoef	Utrecht University of Applied Sciences (HU) Delft University of Technology (TU Delft)	Lector Building Future Cities at the HU and a senior researcher at the Department of Management in the Built Environment at the TU Delft
Arjan Walinga	Bouwend Nederland	Expert BIM and supply chain management at Bouwend Nederland. Bouwend Nederland is a trade association for the construction and infrastructure sector.
Rob Zwart	Dura Vermeer Infra ICT	Information manager at Dura Vermeer and specialized in process management and business-IT alignment.

Table 6 - Interview respondents