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CONTROL TOWER APPROACH TO IMPROVE URBAN CONSTRUCTION LOGISTICS

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Abstract

In many countries the construction industry is responsible for much of freight transport and emissions. In recent years, insight has been gained into the application of various logistics solutions, which have often proven to be successful in reducing construction transport movements and emissions in and around cities. Further steps could be taken to advance information exchange and supply chain collaboration in construction logistics. Supply chain control towers have been deemed to improve supply chain management in individual construction projects, as well as on an area level including multiple projects and supply chains.

The goal of this research has been to lay the foundations and demonstrate the added value of applying the concept of the Construction Logistics Control Tower (CLCT) in urban construction logistics. The research has investigated how CLCTs can help to exchange data and information effectively in order to improve decision making, and reduce negative effects of construction transport.

First a stakeholder analysis looked into the motivations of stakeholders in applying CLCTs. Workshops and surveys provided insight into individual motivations of stakeholders. Preferably stakeholders appreciated insight into the current state of affairs and to use this information to improve logistics efficiency, for a better financial return individually. On the other hand there was appreciation among stakeholders also for CLCTs that are area-oriented and of general use for all.

A case study among selected stakeholders focused on optimizing logistics and applying centralised control by analysing and integrating the logistics of simultaneous construction projects in the centre of Amsterdam. The study demonstrated the added value of centralised logistics management to reduce transport movements for the construction projects, optimize resource usage, and improve the logistics management of the projects.

Keywords: urban construction projects, supply chains, logistics, transport analysis, joint scheduling.

1. Introduction

The construction sector is encountering an array of challenges such as addressing global and regional housing shortages, and climate change. In Europe, particularly in the Netherlands, additional complexities exacerbate the situation. Firstly, emissions must be reduced throughout the entire process, from construction to logistics. Secondly, costs are increasing due to global trade issues and more stringent building regulations. Thirdly, while the sector is swiftly adopting new building techniques, it faces numerous obstacles in digitization. Enhancing coordination and collaboration within the construction supply chain could offer a viable solution to these challenges.

Control towers have been deemed to solve logistical problems. Definitions and applications of a control tower appear to be diverse [1]. An early definition by Bleda et al. [2] was: ”A service control tower acts as a centralized hub that uses real-time data from a company’s existing, integrated data management and transactional systems to integrate processes and tools across the end-to-end supply service chain and drives business outcomes.” A more recent definition is: ”An organizational system which uses IT to optimize a specific part of the service logistics supply chain” [1]. Control towers have the potential to integrate supply chain activities across different organizations. In the integration process of activities benefits are expected, such as waste reduction, higher efficiency and productivity.

In this paper we focus on a construction logistics control tower (CLCT) specifically focusing on controlling and improving logistics activities in construction projects. Earlier research into practical applications of a CLCT was done in sustainable construction logistics in inner cities [3]. Building on lessons learned in the aforementioned research, we investigate the CLCT in a case study in the city of Amsterdam. In particular highly populated inner cities bring additional challenges for construction activities. The creation of zero-emission zones and limitations on construction transportation are additional restrictions in the already complex situation of urban environments.

2. The Control Tower concept for construction logistics management

The CLCT concept fulfils two needs. On the one hand, there is a need from a societal perspective to reduce specific environmental effects such as emissions, traffic congestion, road damage and incidents. On the other hand, there is also an opportunity to increase the efficiency of construction supply chains and transport movements.

To address further potential advantages, the challenges for urban construction logistics play a role. These challenges are there, mainly due to the effects of construction logistics. The construction industry has issues with the uncertainties surrounding the construction supply chain [4], making urban construction difficult. Currently, contemporary construction logistics need to be realized with no or low emissions; this is possible but requires good planning, good collaboration between stakeholders and new technology [5]. The concept of construction logistics centres or hubs could reduce the burden on inner cities and realize modular construction addressing different interests that motivate industry, clients and government [6].

The core issue lies in the lack of supply chain integration in the construction industry [7]. Although benefits are envisioned, such as reducing costs, removing waste, gaining a competitive advantage, creating value, and improving confidence in planning. Although supply chain management has been researcher and applied in the construction industry, problems in the construction supply chains still exist widely [8]. If a CLCT is going to be applied, some form of supply chain integration would need to occur to solve the problems. However, the construction industry has many Small and Medium Enterprises (SMEs) with more significant scepticism towards supply chain management practices [9]. The considerable fragmentation of parties in the construction supply chain even limits the levels of integration achievable [10]. Therefore, such parties need to be included, not only by mere stakeholder management but by showing the practical benefits of being involved in building CLCT solutions.

Many studies have investigated the potential benefits of supply chain management in the construction industry. Especially in transportation, potential benefits are enormous, since 39 to 58 percent of total logistics costs are attributed to transporting goods [11]. Benefits have been demonstrated in practice, with a transport reduction of 50 to 65 percent in the finishing phase and 80 percent in the structural phase of construction projects [3]. Additional savings as a result of better management of supply chain-wide construction logistics will also result in better on-site logistics performance [12].

A CLCT could be a tool or facilitator of the supply chain management process in the construction industry. Other supply chain control tower applications show that integration requires a combination of technology and coordination to realize an intelligent supply chain [13]. A CLCT could be an open platform, facilitating necessary information for all stakeholders involved in construction projects, and providing information services to residents and the wider public around construction projects [14].

3. Research Method

In this research we have first developed a CLCT reference architecture and tested it with a group of companies and projects. We have applied the enterprise architecture approach by Ross et al. [15] viewing the architecture development basically as a business strategy development. It focuses on a so-called core diagram for long-term enterprise architecture, as we have applied in the next chapter .

We have customised the three steps of the approach: 1) Decide on the operation model for urban construction logistics, 2) Develop the core diagram for a CLCT for multiple construction projects, and 3) Establish an IT engagement model for the construction firms and municipality. For this research however, the emphasis was on the first two steps, as IT implementation is a long-term process in the case of the CLCT, requiring the commitment of stakeholders beyond the construction projects.

We investigated and tested the applicability and effect of the CLCT design in the use case of the logistics of simultaneous urban construction projects in Amsterdam. The consortium included the municipality to construction and logistics companies, and an IT provider. The group provided insights into their current supply chain and logistics and the gains in efficiency and cost savings, when transportation processes would be integrated and controlled, simulated by application of the CLCT.

4. Designing a CLCT: Strategic and operational

In this chapter, we design the CLCT in multiple steps. First, we describe the underlying case fueling the enterprise architecture design, which is infrastructure projects taking place in the historic centre of Amsterdam. Second, we conceptualize the outline of a CLCT with different perspectives and narrow them down to applicable solutions. Third, we transform the outline into a CLCT prototype; an enterprise architecture for a CLCT with two layers: a strategic CLCT and an operational CLCT.

4.1. Strategic Construction Logistics Control Tower

The strategic CLCT focuses long-term on transportation in the construction logistics supply chain. However, based on the functionality needs and requirements described by individual stakeholders, the application of the strategic CLCT is broader. First, we discuss the business processes that the strategic CLCT supports. Then, we explain the functional components that run the CLCT and their interdependencies.

The CLCT mainly supports two functions. The first is the construction coordination and communication function. Usually, a municipality is responsible for keeping a city accessible and functioning according to regular standards. However, they depend on how other stakeholders in the construction landscape cooperate with them, including construction firms, transport firms, local governments and citizens. The strategic CLCT supports the municipality in keeping the city accessible and managing traffic so that hindrances are kept to a minimum while informing stakeholders in case of potential hindrances, and achieving ambitions on a city level such as of sustainable and multimodal transport.

On the other hand the CLCT supports more for-profit-oriented business functions aimed at efficient construction logistics and project management. Construction companies are especially interested in realizing and executing construction processes. However, these are usually triggered by construction clients. A few critical business processes that the strategic CLCT supports are managing construction activities, realizing construction logistics, maintaining built assets and, for some organizations, constructing buildings with circular resources.

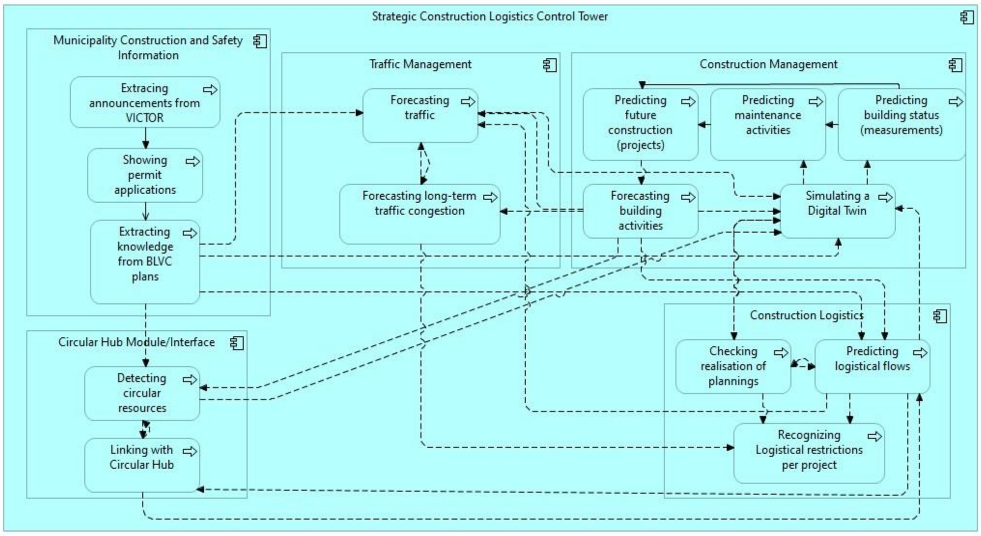


Fig. 1. Strategic CLCT application including internal functions and relations

Figure 1 shows the functions within the strategic CLCT and their interrelations. The individual components all have a unique role in the CLCT. The municipality construction and safety information application is an information source that feeds into other applications like traffic management but also feeds information to the digital twin in the construction management environment. This module and the traffic management module focus more on the societal impact of construction activities. In the validation of the strategic CLCT in the Amsterdam case, particularly this data source has been debated and questioned since the data mentioned is often insufficient, late and not structured to be exported and used to logistics optimisation and management. The municipality is urged to develop useable formats for data inputs from stakeholders and initiators of local construction works, and subsequent data processing into useful parameters for logistics optimisation, visualisation and management of simultaneous projects taking place in urban areas.

The strategic CLCT can be seen as a planning platform for all parties involved to map out projects approximately 1 to 2 years before execution, anticipating project activities and traffic flows. The strategic CLCT functions as a source of information that provides all parties with a common overview of construction schedules and the consequences for construction logistics flows and transports on the level of an urban area or neighbourhood. The intended strategic CLCT keeps the overview up-to-date with the latest changes and predictions of the various construction projects in the city area and shows the cumulative impact of these construction logistics transport flows on existing traffic. This last functionality requires a link with the municipal traffic model.

The strategic CLCT is supported by external technologies and data. Technologies include external applications, standards or data attached to the CLCT. We recognize multiple identifiable technologies that are important. Logistical standards are an absolute necessity for the construction logistics module. As companies have different data standards, so the connection at least to logistics data-sharing standards would be wise to enable the interoperability of the strategic CLCT for all connected users.

4.2. Operational Construction Logistics Control Tower

The second layer of the CLCT is the operational CLCT, which differentiates itself from the strategic CLCT by focusing more on the actual transportation and short-term operational decision-making. We recognize five modules in the operational CLCT: transportation insights, transportation intelligence, water transportation, construction planning and interfaces with external data and resources.

Corresponding to the strategic CLCT, the operational CLCT has a set of functions and technologies that support it (Figure 2). Again, public data from the government can be used to show the current status of the roads, waterways and additional infrastructures such as bridges, traffic intensities, and technical status of roads. However, the most important is that the operational CLCT needs to be linked to the transportation systems of third parties. These systems are transport management systems (TMS) or freight management systems (FMS) and could be linked to the operational CLCT. The CLCT itself could function as a shared transportation control system, but there are also initiatives in which transporters mutually connect their separate systems. These systems should be supported by standards like the Open Trip Model (OTM), such as digital signing of transportation delivery. The water transportation AIS data, which is relatively easy to get and implement, should be used.

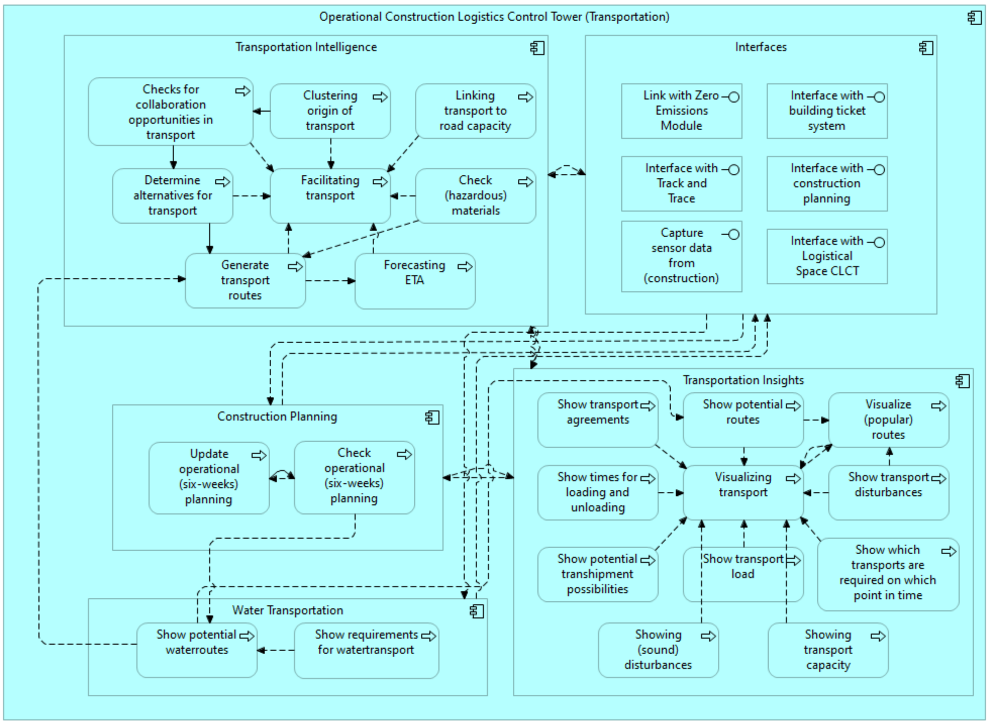


Fig. 2. Operational CLCT application including internal functions and relations

5. Applying the CLCT: case study Amsterdam

5.1. Case study: infrastructure works in the center of Amsterdam

For this research we looked at the use case of infrastructure works in Amsterdam. Amsterdam has a unique history with its inner city, primarily because of the combination of densely populated streets combined with waterways. The Wallen area is hard to access by road, Therefore, the municipality stimulates the use of waterways for logistical purposes. Historically, the waterways were a means of transporting goods to and from the warehouses near the water. Now and in the future, the municipality would like to see the use of these waterways increase to relieve the pressure on the crowded roads and quays, reduce damage to roads, quays and bridges, and to improve the living environment, road safety and accessibility of the area.

In 2020, the City of Amsterdam established the long-term Programme for Bridges and Quay Walls (PBK) to restore 800 out of 1,800 bridges and 200 out of 600 kilometres of quay walls throughout the city. These objects were found to be in critical shape, and in 2020 a quay wall even collapsed completely. The first projects of the PBK program have been commissioned and started in 2023, particularly in the historic city centre. Besides the PBK program, the city also runs a parallel maintenance program to renovate pavements throughout the city. Often quay walls, bridges and pavements, including underground infrastructures are renovated as an integrated cluster per location (Figure 3).

The Amsterdam case involved local infrastructure works and often no digital models of objects are available, but only raw data, rough plans and schematic overview drawings. In the case we did two case studies into the logistics of two sets of three simultaneous nearby projects: two quay wall renovations and one street renovation. The aim of both case studies was to investigate and assess the potential for combined logistics and transport aimed at transport movement reductions. The quest in both case studies was to find logistics optimisation when the logistics of the three project were combined and controlled by a central CLCT rather than controlled individually per project.

Fig. 3. Typical situation of a quay wall and pavement renewal

The first case study was a past case and looked into transport registrations from a hindsight after completion of three simultaneous projects. In this case study the registrations showed a reduction of 7% of empty transports when the loads of the three project were combined when possible. Another 7% reduction was found in case some projects activities and material flows of the three projects would have been shifted in time, and transports could have been combined even more (Figure 4). The conclusions of the first case study were used as inputs for the design of the CLCT.

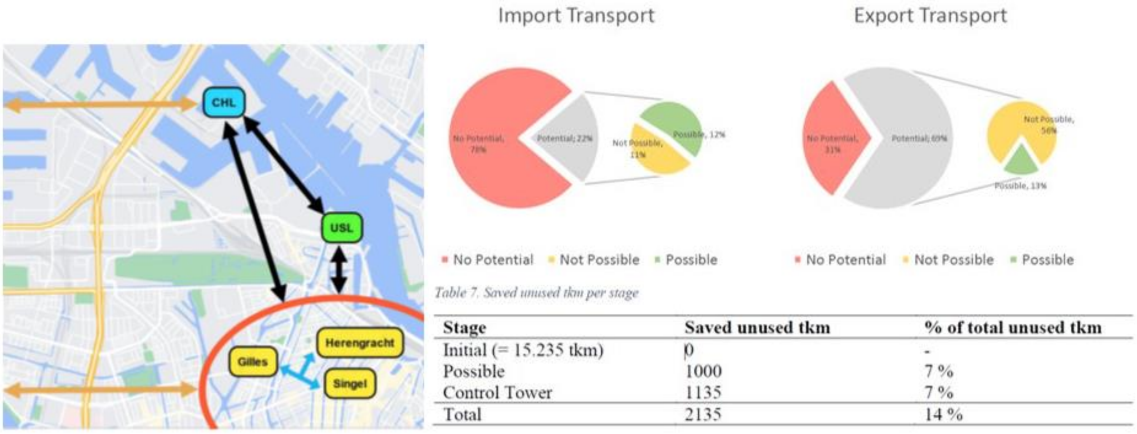


Table 7. Saved unused tkm per stage

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

Fig. 4. First case study in combined transports based on transport registrations from a hindsight

The second case study was a live case based on project planning and bills of materials of three other projects before the start of those projects. In this case study the strategic and operational CLCT design had been applied to make and assess the case of combined transport reductions in advance.

5.2. Applying the strategic CLCT

In the application of the strategic CLCT to the second case study, a number of functions are selected in the functional design diagram below, limiting the case study to those functions of the CLCT that are particularly aimed at reducing transport movements (Figure 5).

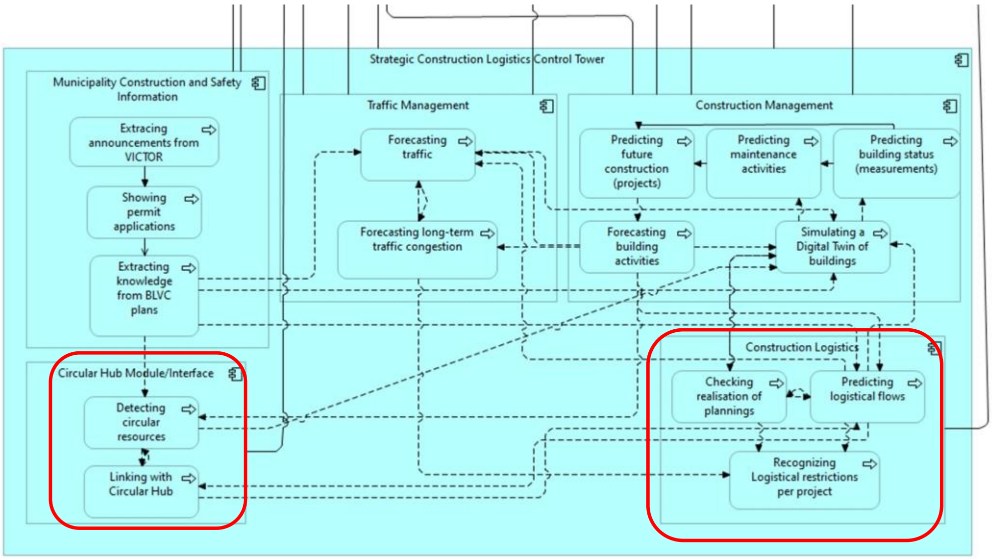


Fig. 5. Selected functions of the strategic CLCT tested in the case study

The strategic CLCT functions particularly served to be able to deduce to-site and return flows based on design and commissioning data from the municipality and engineering firms in the preparation and design phase. In this phase rough calculations and balancing of material and waste flows were possible including estimating the number of transport movements in the conventional base scenario.

5.3. Applying the operational CLCT

For the application of the operational CLCT, a number of functions were also selected in the functional design diagram below, limiting the case study on the operational level (Figure 6).

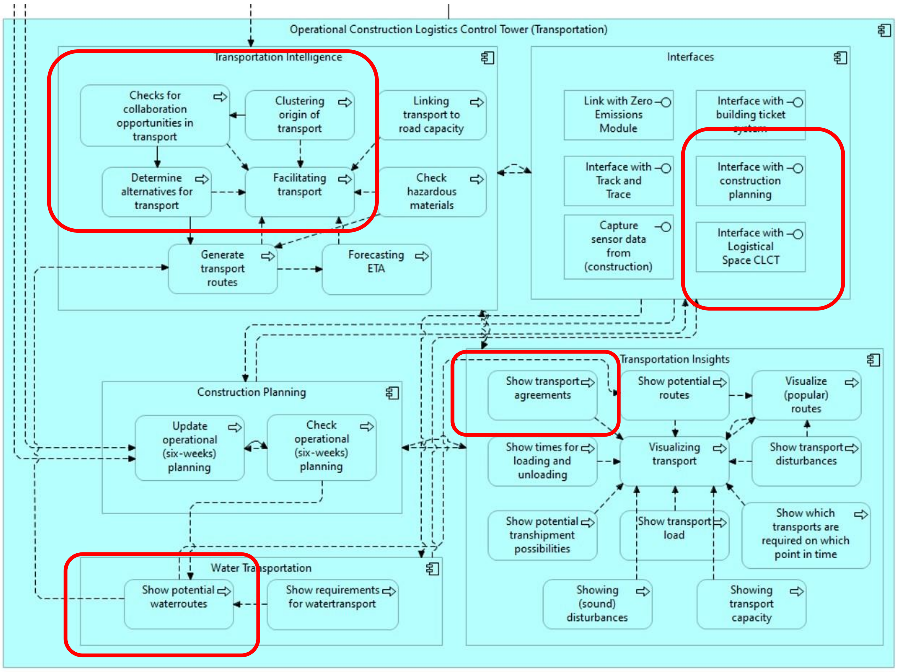


Fig. 6. Selected functions of the operational CLCT tested in the case study

The functions selected particularly represented the ‘trading’ between transports from road to water, between projects, and between to-site and return flows, including logistical space availability to store and buffer incoming materials as well as reusable materials in the proximity of the projects.

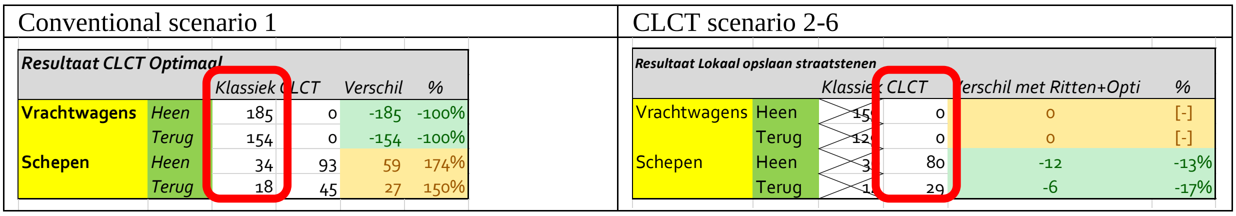
In the case study the planning of the quay walls was taken as a starting point because it involved most of the work; the quay wall work, pavement, underground infrastructures including sewers. Some of the works of the parallel contractors were included in the case study. Most transport already took place via water. The case managed to transfer all remaining land transports to water transports.

The pavement works nearby were less extensive and transport was traditionally done by road. Also those transports could alternatively be carried out via waterways and could be combined in the transport planning of the quay wall works. The planning of some activities have been realistically shifted in time so that they would fit into the quay wall transport planning optimally.

For the assessment modular scenarios have been calculated using the input data from the planning and bills of materials of the projects involved. Every scenario added a logistical measure to improve transport efficiency i.e. reducing transport movements:

1. Classic = separate projects and conventional logistics control, non-full truck and barge loads,
2. Bundling = journey optimization, bundling as many partial loads as possible to and from site,
3. Modal shift = maximizing transport via water,
4. Combining = combining transports between projects,
5. Replanning = replanning project activities so that transports between projects fit even better,
6. Circular = storing reusable materials close by projects for direct reuse among projects.

Each added scenario results in a reduction in the number of ships and trucks. In the case of modal shift scenario some four road transports are replaced by one ship movement.



Conventional scenario 1

Resultaat CLCT Optimaal

		Klassiek	CLCT	Verschil	%
Vrachtwagens	Heen	185	0	-185	-100%
	Terug	154	0	-154	-100%
Schepen	Heen	34	93	59	174%
	Terug	18	45	27	150%

CLCT scenario 2-6

Resultaat Lokaal opslaan straatstenen

		Klassiek	CLCT	erschil met Ritten+Opti	%
Vrachtwagens	Heen	15	0	0	[-]
	Terug	12	0	0	[-]
Schepen	Heen	3	80	-12	-13%
	Terug	1	29	-6	-17%

Fig. 7. Calculations of conventional scenario 1 and CLCT scenario 2-6. Vrachtwagens=lorries. Schepen=ships.

All in all, the reduction from the conventional scenario 1 ‘klassiek' (see figure 7) to the CLCT scenario 2-6 resulted in a 20% reduction in transport (see table 1). This supports the assumption that in classic scenarios and projects individually organize their logistics, many transports are not completely full. In other words, an increasing reduction in the number of transports is possible if multiple projects manage to bundle partial loads, use each other's available loading space, arrange planning in such a way that loads can be bundled, and reusable materials remain on or near the projects for joint reuse by the projects.

Table 1. Comparing scenario 1 (conventional) versus scenarios 2-6 (CLCT)

	Conventional scenario 1	CLCT scenario 2-6
Lorries to site	185	0
Lorries from site	154	0
Barges to site	34	80
Barges from site.	18	29
Total eq. lorries	547	436 = 80%

6. Discussion and conclusion

We have distinguished two versions of the transportation CLCT, i.e., a strategic version that prioritizes long-term planning and aims, and an operational version that anticipates and adapts to short-term processes and project activities. We have taken a selective approach to the CLCT application in a concrete case study. We have critically applied and tested selected functions within the case study both to assess the logistics parameters of actual projects, and comparing the functions to business and project processes as well as data sources of stakeholders. We have found that the CLCT does connect and improves the practice of project stakeholders, and does support joint planning scenarios to improve collective project logistics and reduce transport movements. We have calculated and described the scenarios and their potential benefits for the construction logistics. Additionally, we have observed few potential hindrances and opportunities in implementing the CLCT further, and integrating the CLCT in municipality and firms environments and processes. In the case study presented in this paper a manual approach to the CLCT has showed clear opportunities for improving transport efficiency and sustainability, and reducing hindrance of transports for simultaneous project taking place in an urban area. Further developments and wider application of CLCTs would need more automated approaches and digital technologies.

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