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Design and validation of BIM scenarios, incentives and protocol for construction logistics

Report on the PDEng project BIM and contract provisions

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Executive summary

The main objective of this PDEng project was to stimulate the use of BIM for construction logistics optimization. Construction logistics optimization is very important; the transport of construction goods is a significant contributor of pollution to our environment. Optimization of construction logistics will significantly reduce CO_2 emissions and nuisance to traffic caused by construction related activities. The use of BIM supports construction logistics optimization, and therefore, it is important to stimulate organizations to use BIM for this purpose.

To achieve these objectives, three products were developed: ① BIM scenarios for construction logistics, ② incentives for applying BIM scenarios for construction logistics, and ③ addendum to the BIM protocol. Each of these products will be described next.

① BIM scenarios for construction logistics describe how BIM could be used to support construction logistics optimization within a specific collaboration setting, and their potential benefits for the participating organizations. Each BIM scenario is composed of multiple BIM uses that describe a certain way of applying BIM to support construction logistics optimization.

Two BIM scenarios for construction logistics were designed. BIM scenario #1 is *Data exchange using BIM*, in which the model is used for storing and exchanging data. The model serves as a repository of data that can be retrieved by multiple applications used by project partners and/or project disciplines working in the same project. Information is entered once, is consistent (uniform) and non-redundant. Through this BIM scenario, errors in the design (drawings) and the lack of correct information are addressed, which results to less disturbances in the execution and logistics processes. Furthermore, construction partners can generate information regarding what, in which context and how much materials should be delivered to the construction site. As such, this scenario is a major precondition for achieving optimal construction logistics.

BIM scenario #2 is *4D modeling*, in which the 3D geometries and location of objects in the model are linked to temporal information, such as the timings of their production, delivery or construction. An advantage of model-based scheduling is that it captures the spatial components related to activities, and directly links activities with the design. Through this link, the schedule can remain in sync with the design, and stakeholders are able to easily understand the schedule, evaluate its feasibility and its impact on logistics. Through this BIM scenario, construction partners can generate information regarding when and in which time slots deliveries should take place. When BIM is linked with GIS, construction partners can also generate information regarding where in the construction site should the materials be delivered, and which delivery routes and access points to take for an optimal transportation and handling of materials.

② The incentives for applying BIM scenarios for construction logistics aim to motivate an organization to the intended use of BIM. The incentives contain guidelines for formulating and

applying rewards and penalties for the intended use of BIM for construction logistics. They can be applied in an integrated collaboration setting.

Two incentives for applying BIM scenarios for construction logistics in a project were designed. Incentive #1 is *Sharing of savings*. The prime contractor could pay the designer for the BIM activities related to applying measures or strategies to optimize design and logistics (such as adjusting the BIM model, and/or adding information to the model). In addition, actual savings realized by the prime contractor during the execution phase resulting from these measures or strategies will be shared with the designer (according to a predetermined percentage of distribution). This would motivate the designer to ensure that the BIM model is created in a manner that it could be used to realize the savings (during the execution phase).

Incentive #2 is the *MEAT criterion 4D BIM and construction logistics*. The goal of linking 4D models to the MEAT criterion Construction logistics is to steer the prime contractor to optimize construction logistics and minimize nuisance to the public during the execution phase. The linking of 4D models contributes to this goal by: forcing the prime contractor to thoroughly think about and work out his MEAT strategies using 4D modeling; supporting the prime contractor in proving and demonstrating the effectiveness of MEAT strategies; and supporting the client's tender and evaluation committee in understanding the (effects of) proposed MEAT strategies and consequently be more able to steer the prime contractor to the desired effects. This creates the incentive for the prime contractor to optimize construction logistics and reduce CO_2 emissions, for a better chance of being awarded the contract.

③ The addendum contains the recommendations for aligning the existing BIM protocols with (incentives for) the use of BIM for construction logistics. The resulting addendum contains agreements regarding the delivery of information needed for the BIM uses for construction logistics and the incentives linked to the use of BIM. The delivery of information was designed in accordance with the Information Delivery Scheme for 4D BIM (ILS 4D BIM), for which a conceptual design was also developed by the PDEng trainee. The addendum was then tested through expert opinion. Experts were asked to evaluate the addendum. They evaluated the addendum positively, and no changes were made to the addendum.

In conclusion, the three products contribute significantly to the reduction of nuisance and CO2 emissions by stimulating and guiding the use of BIM for construction logistics optimization. This is evidenced by the experience from the case studies and supported by the opinion of practitioners, who were interviewed and participated in the workshops.

As such, clients and construction partners are recommended to apply and further develop these products in practice. Since the use of 4D BIM for construction logistics optimization is still scarce in practice, it is necessary to continue research and obtain insights into how to request and apply 4D BIM in an infrastructure project in an optimal way. The knowledge from this PDEng project must be transferred to environment managers, contract managers and project managers to obtain potential projects for the follow-up research. These managers should identify infrastructure projects, and in these potential projects, the clients should request the use of 4D BIM in the tender phase. Most importantly, lessons learned from these projects should be centralized to facilitate learning and uptake of 4D BIM in the construction sector.

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Chapter 1. Introduction

In this chapter, the PDEng design project will be introduced. First, in section 1.1, the background of the PDEng project will be presented. Second, in section 1.2, the project scope and design methodology will be outlined. Last, in section 1.3, the structure of the report will be given.

"One must require from each one the duty which each one can perform."

-Antoine de Saint-Exupery, The Little Prince

1.1 BACKGROUND

The transport of construction goods is a significant contributor of pollution to our environment. According to a 2012 study cited by the European Commission, up to one-fifth of the total CO_2 emissions in the European Union comes from transport alone (Schroten, 2012). A staggering 10.000 megatons of CO_2 are emitted by road and shipping transport annually (IMO, 2014; Schroten, 2012), and as much as one-fourth of this is caused by the transport of construction goods (Van Merriënboer & Ludema, 2016).

Optimization of construction logistics will significantly reduce CO_2 emissions and nuisance to both road and shipping traffic caused by construction related activities. Construction logistics is “a process of strategically managing the procurement, movement and storage” (Wegelius-Lehtonen, 2001, p. 108) of resources (and the related information flows) to, from and within the construction site. Main activities consist of planning, organization, management and control of resources and related information flow (Cooper, Lambert, & Pagh, 1997; Serra & Oliveira, 2003). Acquiring accurate and complete information in a timely and correct manner is critical to the successful planning and execution of construction logistics (Agapiou, Clausen, Flanagan, Norman, & Notman, 1998; Vrijhoef & Koskela, 2000).

The optimization of construction logistics has become even more important and complex due to recent developments in the construction industry. The increased degrees of specialization and industrialization, and the shift to inner-city construction have led to challenges in minimizing disruptions to the workflow on site, minimizing disruptions to traffic and urban functions, and minimizing logistics costs, inventory and lead time (Bemelmans, 2012; de Vries & Ludema, 2012; Navon & Berkovich, 2006).

The use of Building Information Model (BIM) helps address these challenges and supports the optimization of construction logistics (Eastman et al., 2011; Salazar, Mokbel, Aboulezz, & Kearney, 2006; Trebbe, Hartmann, & Dorée, 2015). BIM is a digital ‘intelligent’ object-oriented model of a construction project and the related construction processes, which includes both graphical and non-graphical data (Adriaanse, Voordijk, & Dewulf, 2010). It can support, fill-in and optimize the communication and collaboration processes through transmission, clarification and provision of information to all the involved participants across the various trades in the construction project (Adriaanse et al., 2010).

If organizations input the necessary data in BIM, it can contain all relevant information about the project, which can be used for production, storage, transportation, tracking, and installation of materials (Salazar et al., 2006). Organizations can have access to accurate and complete information when they are needed. In addition, organizations working together can use BIM tools to develop well-coordinated project schedules, and optimize the flow of resources to, from and within the construction site (Irizarry, Karan, & Jalaei, 2013).

For the full benefit of BIM for construction logistics to be realized, the participation of the client, prime contractor, designers, subcontractors and suppliers in the intended use of BIM is essential (Eastman et al., 2011; Irizarry et al., 2013). However, organizations may choose not to use BIM (in the intended way) for optimizing construction logistics in a project. Contractual arrangements can force an organization to the intended use of BIM for construction logistics, but previous research has found that, obligatory participation does not facilitate genuine collaboration, as organizations often make the minimum effort to fulfill their contractual obligations (Adriaanse et al., 2010; Chang & Howard, 2016). In addition, forcing organizations to the intended use of BIM can come at a large price for the organization demanding the use of BIM.

Therefore, it is important that organizations are motivated to use BIM for construction logistics optimization. In addition, organizations must make clear agreements with each other regarding how information is created, stored and exchanged, to enable the (re)use of information (Adriaanse et al., 2010; Chao-Duivis, 2009; Eastman et al., 2011; Glick & Guggemos, 2009).

1.1.1. Incentives for the use of BIM for construction logistics

An organization can be motivated to the intended use of BIM for construction logistics by incentivizing the use of BIM for construction logistics. Incentives to the use of BIM for construction logistics can be divided into three groups (see Figure **1**).

Figure 1. Groups of incentives for the use of BIM for construction logistics.

By itself, the *benefits* of BIM for construction logistics perceived by an organization are an incentive to use BIM for construction logistics. However, when an organization is not aware of the benefits of BIM for construction logistics, then the organization may not be willing to invest resources and to overcome barriers to use BIM for construction logistics. It is important that organizations are aware of the benefits of BIM for construction logistics, to motivate them to the intended use of BIM.

The possibilities and benefits of using BIM can be maximized by an *integrated collaboration setting*. Collaboration setting pertains to both: 1) the contract model between the client and the prime contractor, and 2) the level of supply chain integration between the prime contractor, designer, subcontractor and supplier. An integrated collaboration setting offers possibilities and incentives for: 1) optimizing construction logistics; 2) regulating the use of BIM in a construction project; and 3) applying BIM uses for construction logistics.

The integrated collaboration setting offers possibilities and incentives for the use of BIM for construction logistics. However, these possibilities and incentives are not always created and applied in reality. Moreover, despite the critical role of incentives in economic decision making, there is a lack of research addressing incentives within the topic of BIM (Chang & Howard, 2016; Eastman et al., 2011). Therefore, it is important that organizations formulate and apply incentives, such as rewards and penalties, that are specific to the intended use of BIM for construction logistics.

When the incentives to the use of BIM for construction logistics are created, it is important that they are anchored to the *contract* that organizations enter into with each other. The BIM protocol is an important document for specifying agreements related to BIM. The BIM protocol is a document that is added or attached to the contract between the organizations participating in the use of BIM.

1.1.2. Design objective and products

As discussed above, it is important that organizations become aware of how BIM can be used to support the optimization of construction logistics, that the necessary incentives are created, and that contractual arrangements are available to allow and motivate organizations to the desired use of BIM for construction logistics.

In line with this, the main objective of this PDEng design project is <u>to incentivize the use of BIM for construction logistics</u>, by: 1) making the potential benefits of BIM for construction logistics known, 2) creating incentivizes for applying BIM uses for construction logistics, and 3) aligning contractual arrangements to (incentives for) BIM uses for construction logistics.

Three products, which correspond to the three objectives of this PDEng project, were developed:

Product 1: BIM scenarios for construction logistics
BIM scenarios for construction logistics describe how BIM could be used to support construction logistics optimization within a specific collaboration setting, and their potential benefits for the participating organizations. Each BIM scenario is composed of multiple BIM uses that describe a certain way of applying BIM to support construction logistics optimization.

The BIM scenarios illustrate how BIM could be used to support construction logistics optimization, with the aim of increasing organizations' awareness of the potential benefits of BIM for construction logistics. Benefits of BIM uses for construction logistics positively influence an organization's intention to apply BIM uses for construction logistics in a project (Adriaanse et al., 2010). They also serve as an important input for Product 2, by defining the needs and requirements of each organization in relation to construction logistics and BIM, which is a necessary step in designing effective incentives (Liska & Snell, 1992).

Product 2: Incentives for applying BIM scenarios for construction logistics
The incentives for applying BIM scenarios for construction logistics aim to motivate an organization to the intended use of BIM. The incentives contain guidelines for formulating and applying rewards and penalties for the intended use of BIM for construction logistics. They can be applied in an integrated collaboration setting. They also serve as an important input for Product 3: Addendum to the BIM protocol.

Product 3: Addendum to the BIM protocol
The addendum contains the recommendations for aligning the existing BIM protocols with (incentives for) the use of BIM for construction logistics. It is important that organizations are kept to the terms of the contractual arrangements related to the use of BIM for construction logistics. This can be achieved by linking and aligning the BIM protocol with both the intended use of BIM for construction logistics, and the incentives for applying BIM uses for construction logistics.

In the next section, the methodology followed for designing the three products will be discussed.

1.2 PROJECT SCOPE AND DESIGN METHODOLOGY

In this section, the project scope and design methodology will be outlined. The project scope will first be discussed in subsection 1.2.1, followed by the design methodology in subsection 1.2.2.

1.2.1. Project scope

In this subsection, three limitations to the scope of the PDEng design project will be discussed: 1) focus on financial incentives; 2) focus on the contract model; and 3) focus on levels of supply chain integration.

Incentives: Focus on financial incentives – There are two major types of incentives: psychological and financial (Liska & Snell, 1992, p. 667). Psychological incentives are aimed towards increasing an individual's sense of satisfaction with his/her work, sense of recognition and sense of responsibility (Liska & Snell, 1992; Wesel, 2006). Financial incentives use monetary rewards to motivate individuals to increase performance or production (Liska & Snell, 1992). Between psychological and financial incentives, psychological incentives are more difficult to measure. Hence, they are out of the scope of this report. Therefore, a focus on financial incentives used in the construction industry will be made.

In this PDEng project, the trainee considers the relationship between the client, prime contractor, designer, subcontractor and supplier. The trainee defines two layers of relationships between these organizations (as illustrated in Figure 2). The first layer relationship is the relationship between the client and the prime contractor (and the designer, in a traditional contract model). The second layer relationship is the relationship between the prime contractor and the subcontractors and suppliers (and designers, in an integrated contract model).

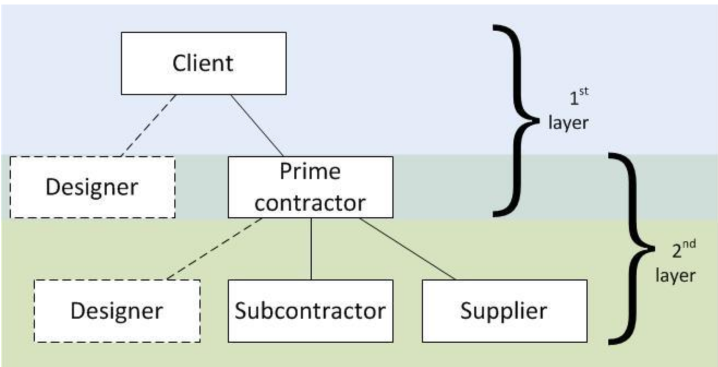


Figure 2. Two layers of relationships considered in this PDEng project.

1st layer relationship: Focus on the contract model – In the 1st layer relationship (client – prime contractor), the focus was on the contract model. In this PDEng project, the contract model considered was the integrated contract model (UAC 2012/Design and Construct).

2nd layer relationship: Focus on levels of supply chain integration – In the 2nd layer of relationship (prime contractor – designers, subcontractors and suppliers), the focus will be on the level of supply chain integration. There are four levels of supply chain integration: independent, loosely coupled, closely connected and integrated. To determine the level of supply chain integration between the prime contractor, on the one side, and the designers, subcontractors and suppliers, on the other, the trainee used a model for determining the level of supply chain integration in the construction industry, which was developed by Vrijhoef (2011). The model deals with the major issues of economic governance, production management, inter-firm governance and social governance of integrated supply chains, represented by ten factors of analysis (Vrijhoef, 2011, pp. 81-83).

Among the ten factors of analysis, four factors of analysis were chosen (see Table 1) to be the most relevant to the three topics of BIM, construction logistics, and collaboration setting (reasons are given in Table 1). These four factors of analysis will be used to measure the level of supply chain integration in a construction project.

Table 1. Factors of analysis included in the scope of this project (Vrijhoef, 2011, pp. 81-83).

Factors of analysis	Description
Information exchange	Information exchange refers to the information systems and their alignment. It also refers to information visibility (how much information can be received/viewed) and transparency (which information can be received/viewed). In an integrated level of information exchange, there is full visibility and transparency of information, and organizations in the supply chain share the same information standards and database. This factor of analysis is related to the PDEng project because it measures the level of integration of information systems and their alignment, which are critical to the successful use of BIM for construction logistics.
Planning and logistics control	Planning and logistics control refer to how the planning and logistics are coordinated and integrated. In an integrated level of planning and logistics control, more advanced logistics strategies, such as just-in-time (JIT) production and delivery, are possible. This factor of analysis is related to the PDEng project because it measures the level of integration of construction logistics, which poses possibilities and incentives for applying BIM uses for construction logistics.
Partner sourcing and collaboration strategy	Partner sourcing and collaboration strategy refer to the scope of the contract between the prime contractor, on the one side, and the designers, subcontractors and suppliers, on the other side. In an integrated partner sourcing and collaboration strategy, there are long-term relationship contracts with designers, subcontractors and suppliers that outline joint partnering philosophy. Risks and rewards are shared, and there is an open cost price agreement. This aspect is related to collaboration setting because it measures the level of integration of the contract between organizations, which poses possibilities and incentives for applying BIM uses for construction logistics.
Product development and design	Product development and design refer to the scope of involvement of subcontractors and suppliers in the development of the design and in the development of standard components. In an integrated product development and design, subcontractors and suppliers are fully involved in design development. Modular design is applied, and suppliers' products are standard design parts. This aspect is related to the PDEng project because it measures the level of integration of the moment and scope of involvement of organizations in a construction project, which poses possibilities and incentives for applying BIM uses for construction logistics..

1.2.2. Design methodology

The methodology followed in this PDEng project was the design cycle proposed by Wieringa (2014). The design cycle consists of three phases: problem investigation, treatment design and treatment validation. The design cycle is part of a larger cycle called the engineering cycle (shown in Figure 3), in which the result of the design cycle is implemented in the real world. Due to constraints in resources, treatment implementation in the real world was outside the scope of the PDEng project.

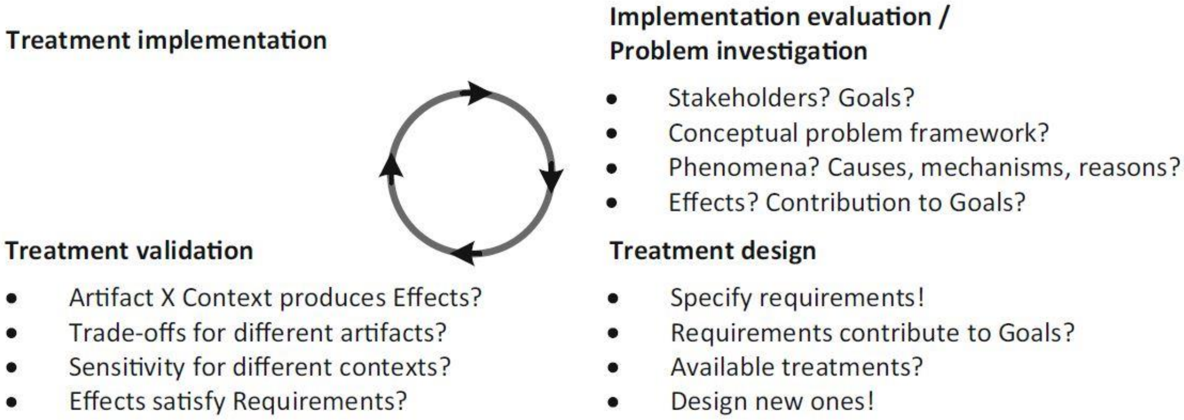


Figure 3. The engineering cycle (Wieringa, 2014, p. 28).

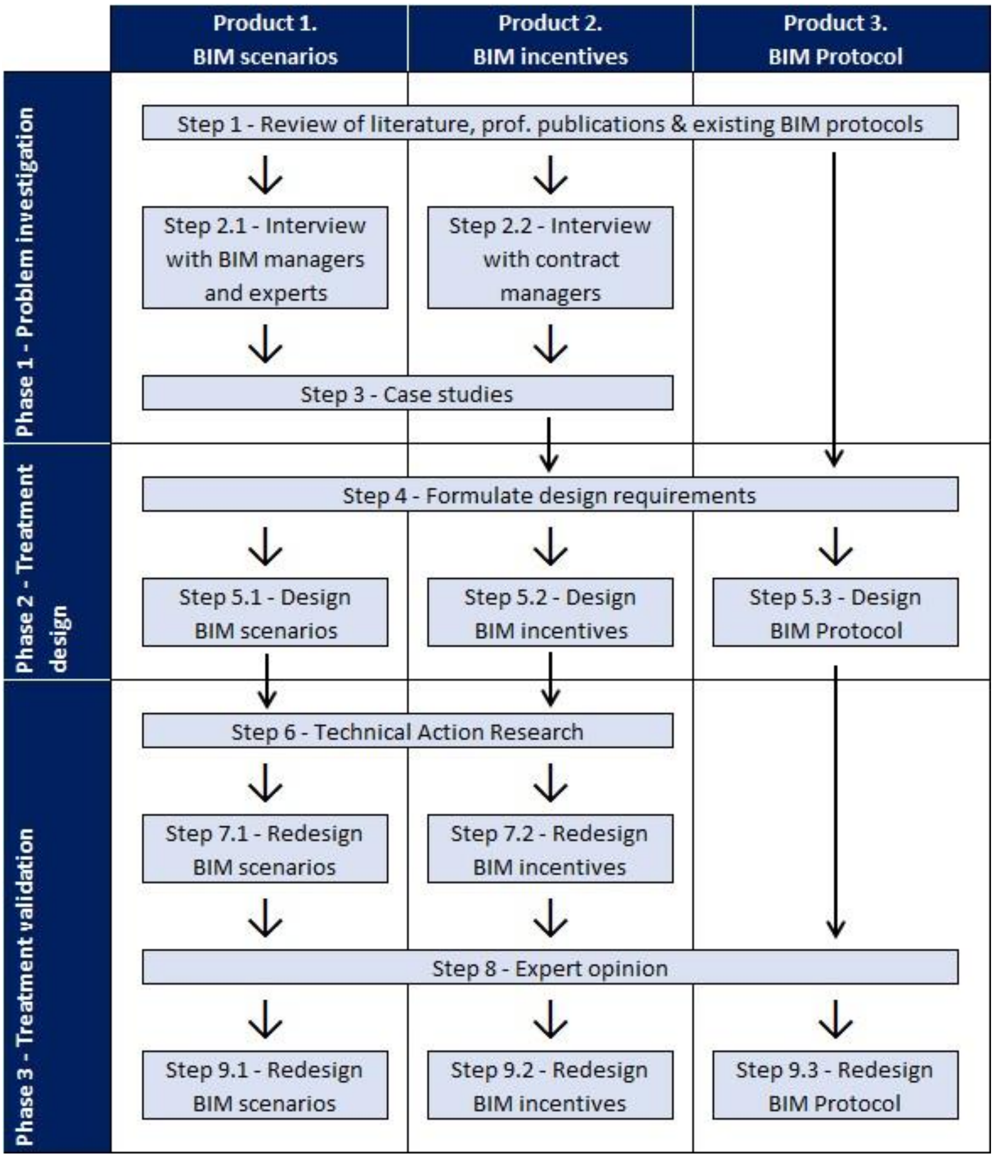


Figure 4. Overview of the methodology.

Each phase of the design cycle is composed of distinctive steps, each of which build upon the results of the steps preceding it. Each of the steps were also conducted for each of the three products. Figure **4** shows an overview of the phases and steps followed in this PDEng project.

Problem investigation

In the problem investigation phase, the PDEng trainee carried out three steps for each of the three products. Table **2** lists the objectives of each step for each design product.

Table 2. Objectives of the steps in the problem investigation phase.

	Product 1. BIM scenarios for construction logistics	Product 2. Incentives for applying BIM scenarios for construction logistics	Product 3. Addendum to the BIM protocol
Step 1. Review of literature, professional publications and existing BIM protocols	-Determine logistics requirements of organizations -Determine (current and future) BIM uses and their potential benefits for construction logistics	-Determine possible incentives for applying BIM uses for construction logistics	-Identify common agreements included in existing BIM protocols in the Netherlands -Identify agreements that must be added to existing BIM protocols
Step 2. Interviews	-Validate (and append) the list of BIM uses, and their potential benefits for construction logistics obtained from step 1	-Validate (and append) the list of incentives obtained from step 1	
Step 3. Case study	-Validate (and append) the logistics requirements of organizations -Investigate why organizations chose (not) to apply BIM uses for construction logistics (in the intended way), specifically the benefits (and disadvantages) of the BIM uses for construction logistics perceived by each organization	-Investigate how organizations can be motivated to apply BIM uses for construction logistics in the intended way	
Outputs of this phase	-Logistics requirements of organizations -Reasons for choosing (not) to apply BIM uses for construction logistics, specifically the benefits (and disadvantages) of BIM uses for construction logistics perceived by each organization	-Possible incentives for applying BIM uses for construction logistics, and how these incentives can be applied to motivate organizations to apply BIM uses for construction logistics in the intended way	-Agreements that must be added to existing BIM protocols

Treatment design

After the problem was investigated, the treatment design phase was started. In this phase, two steps were carried out for each of the three products. The first step in this phase is to define the functional requirements of the each of the products, based on the results of the problem investigation. This step will result to a function tree for each of the three products. The next step in this phase is to design each of the products. This is done by allocating solutions to each function in the function tree.

Treatment validation

The last phase in the design cycle is the treatment validation phase. The main goals of this phase were to test whether the designed products achieved the targeted performance, and to redesign the products according to the results of the test. The methods in the treatment validation phase followed in this PDEng project were:

1) Technical action research (TAR)
2) Expert opinion

TAR is a research methodology where a designed solution is tested in practical situation to improve the situation and to learn from it. TAR was performed in the case study New Lock Terneuzen. The TAR resulted to descriptions and explanations about the effectiveness of products 1 and 2 (BIM scenarios for construction logistics, and incentives for applying BIM uses for construction logistics, respectively). Products 1 and 2 were then redesigned based on the results of the TAR (1^{st} redesign step).

After the 1^{st} redesign step, the opinion of various experts on the effectiveness of the three products were gathered. Two sessions were conducted: one for product 1 (BIM scenarios for construction logistics), and another for products 2 and 3 (incentives for applying BIM uses for construction logistics and addendum to the BIM protocol, respectively). Based on the opinion of the experts, all three products were redesigned (2^{nd} redesign step), resulting to the final deliverables of the PDEng project.

1.3 STRUCTURE OF THE REPORT

In the next chapters of the report, the results of each of the phases of the design cycle will be discussed. Figure 5 shows an overview of the following chapters and sections in the report. Each chapter corresponds to a phase in the design cycle, and each section of that chapter corresponds to the steps conducted within that phase.

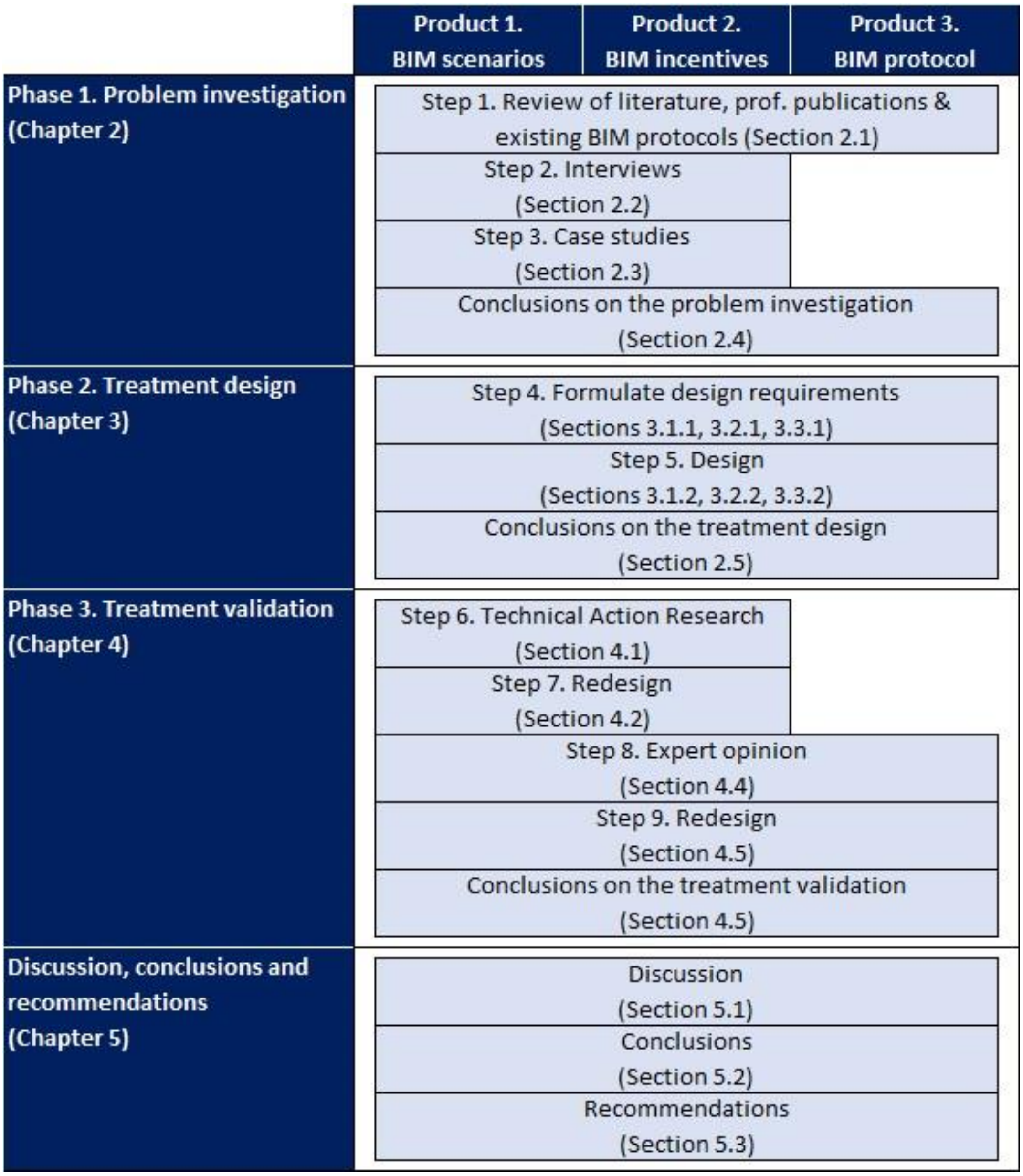


Figure 5. Chapters and sections of the report.

Chapter 2. Problem investigation

In this chapter, the results of the problem investigation will be discussed. The three main objectives of the problem investigation were to investigate how BIM could support construction logistics optimization, why organizations choose (not) to apply BIM uses for construction logistics, and how (and which) incentives could be applied to motivate organizations to apply BIM uses for construction logistics.

This chapter is structured into sections that correspond to the steps in the problem investigation phase. In the first section, the results of the review will be discussed (section 2.1), followed by the results of the interviews (section 2.2). The results of the case study will be presented in section 2.3. The chapter ends with the conclusions on the problem investigation in section 2.4.

"If a problem is fixable, if a situation is such that you can do something about it, then there is no need to worry. If it's not fixable, then there's no help in worrying. There is no benefit in worrying whatsoever."

-Dalai Lama XIV

2.1 Review of literature, professional publications & existing BIM protocols

The objectives of the review for each of the design products, as discussed in subsection 1.2.2, are listed in Table **3**. In this section, the results of the review in the problem investigation phase will be discussed. The discussion is structured into subsections that correspond to the three products of the PDEng project. Subsections 2.1.1, 2.1.2, and 2.1.3 contain the results of the review on BIM uses for construction logistics, incentives for applying BIM uses for construction logistics, and BIM protocols, respectively.

Table 3. Objectives of the literature review.

	Product 1. BIM scenarios for construction logistics	Product 2. Incentives for applying BIM uses for construction logistics	Product 3. Addendum to the BIM protocol
Step 1.	-Determine logistics requirements of organizations -Determine (current and future) BIM uses and their potential benefits for construction logistics	-Determine possible incentives for applying BIM uses for construction logistics	-Identify common agreements included in existing BIM protocols in the Netherlands -Identify agreements that must be added to existing BIM protocols

2.1.1. Literature review on BIM uses for construction logistics

An objective of this literature review was to identify BIM uses that can be used to support and optimize construction logistics. *BIM use* refers to “a unique task or procedure on a project which can benefit from the integration of BIM into that process” (Computer Integrated Construction Research Program, 2010, p. 4). BIM use is also referred to in other literature as BIM Use Cases (Computer Integrated Construction Research Program, 2010) or BIM Application Areas (Eastman et al., 2011).

To compile a list of BIM uses for construction logistics, a list of all BIM uses had to be obtained first. A PDEng project on BIM maturity (Siebelink, Adriaanse, & Voordijk, 2015) came up with a list of all BIM uses based on literature review, interviews, and case study (see Appendix B).

The BIM uses that can be used to support construction logistics optimization were then selected from the list of all BIM uses. For this, it was important to first determine the needs of the client, prime contractor, designers, subcontractors and suppliers that are related to construction logistics. By identifying the construction logistics tasks of each organization, their (information) needs, characteristics of the tasks and bottlenecks, it was possible to determine the logistics requirements of organizations and consequently determine which BIM uses can address these needs.

The logistics requirements in the tender-design phase are present in projects with integrated contracts, such as Design-Build. Some tasks of the prime contractor can be performed in the tender to design phase in the case of integrated contract models, otherwise they shift to the project engineering phase. Therefore, organizations may have additional logistics requirements in projects with integrated contracts above the general logistics requirements in projects with traditional contracts.

The list of logistics tasks, information needs and common bottlenecks for each organization resulting from the literature review can be found in Appendix A. Based on this list, the PDEng trainee determined and formulated the logistics requirements of each organization. An overview of the formulated logistics requirements for each phase and organization is given in Table **4**. These requirements will be verified by practitioners in the case studies in section 2.3.

Table 4. Logistics requirements of organizations for each construction phase.

		Logistics requirements
Tender-Design phase (FOR INTEGRATED CONTRACTS)	Client	• Visualize the effects of alternative construction phase planning on traffic flows and the availability of public and temporary roads
	Prime contractor	• Efficiently analyze and compare effects of alternative construction phase planning on traffic flows and the availability of public and temporary roads. • Optimize construction method and construction sequence, and eventually optimize design
	Designer	• Align designs from various disciplines, which results to less design errors and consequently, less disruptions to the execution and logistics process. • Consistently process design changes in all drawings, which results to less errors in drawings and consequently, less disruptions to the execution and logistics process. • Align the design with the circumstances on site.
Project engineering phase	Prime contractor	• Clearly visualize and communicate the location, context and quantity of specific elements with certain specifications (what, where and how much). • Independently generate and use information out of the design. • Align production models from various disciplines with each other, which results to less design errors and consequently, less disruptions to the construction and logistics process. • Determine what, when and how much should be delivered, and eventually optimize delivery options
	Subcontractors and suppliers	• Independently generate and use information out of the design. • Determine what, when and how much should be delivered, and eventually optimize delivery options
Execution phase	Prime contractor	• Monitor if orders will be delivered on time, and view the consequences of delivery time on construction activities. • Manage the stock on site. • Align on a detailed level which party is working where and when. • Optimize use of space on site.
	Subcontractors and suppliers	• Independently generate and use information out of the design. • Determine what, when and how much should be delivered, and eventually optimize delivery options

The trainee selected the BIM uses from the list of all BIM uses that can be used to address the logistics requirements listed in Table **4**. This resulted to 11 BIM uses for construction logistics listed in Table **5**. How these 11 BIM uses were selected is shown in Appendix C. An excerpt of this appendix is given in Figure **6**.

Table 5. List of BIM uses for construction logistics from literature.

BIM uses for construction logistics from literature	
1	Data exchange with other project partners/ project disciplines
2	Generating quantities from the 3D model
3	Coupling of 3D model to a planning (4D modeling)
4	Costs estimation with the 3D model (5D modeling)
5	Labelling and numbering of objects for production, installation and logistics
6	Positioning via laser and machine guidance techniques
7	3D coordination (management of subcontractors and suppliers)
8	Support of lean sessions with the model
9	Monitoring of logistics via RFID-tags and/or barcodes
10	Coupling of BIM with GIS (Geographic Information System)
11	3D modeling of temporary structures

1 DATA EXCHANGE WITH OTHER PROJECT PARTNERS/ PROJECT DISCIPLINES

Description and possible benefits
A process in which the model is used for exchanging data. The model serves as a repository of data that can be retrieved by multiple applications used by project partners/ project disciplines working in the same project (Eastman, Teicholz, Sacks, & Liston, 2011). Data exchange through BIM could eliminate manual copying of partial project data, which could lead to the following benefits for construction logistics (Eastman et al., 2011):

It encourages iteration during design, which is necessary for finding the optimal alternative for construction logistics
It reduces errors and inconsistency of information, which leads to smooth execution of activities
It increases automation of business processes, which reduces cycle times and overall time required for construction operations.

Can support the following logistics tasks and address the following common bottlenecks
During the **design phase**, this BIM use can support the **designer** in analyzing alternative structural designs and material utilization. It can also support the **designer, subcontractors and suppliers** in incorporating the use of prefabrication in the design. During the **execution phase**, this BIM use can support the **prime contractor** in updating schedules and plans, and in managing documentation. When **subcontractors and suppliers** are given access to the model, this BIM use can support them in preparing the Bill of Materials, engineering design and creating shop drawings. Throughout the construction process, this BIM use can address the long search for requisite information, incorrect documents and reduce errors and inconsistency of information.

2 GENERATING QUANTITIES FROM THE 3D MODEL

Description and possible benefits
A process in which the model is used to generate the quantity takeoff of materials. Quantities can be automatically extracted from the model; most BIM tools can count the number of items, and calculate spatial quantities – like length, area, and volume – using the element's geometric properties. The information can be used in all phases of the project: (preliminary) cost estimation, scheduling, purchasing, and cost reporting.

Extracting the information from the 3D model depends on how elements are modeled and the measurements parameterized. For example, when the model contains detailed element information (such as the manufacturer's code, and weight per meter), then a quantity takeoff of specific items can be generated by identifying the relevant components, extracting the required quantity, generating the item description, and counting the number of occurrences.

Can support the following logistics tasks and address the following common bottlenecks
During the **design phase**, this BIM use can support **prime contractor** in the preparation of logistics assessment. During the **preparation/ project engineering phase**, this BIM use can support the **prime contractor** in preparing the Bill of Materials and the schedules and charts of labor and equipment utilization. During the **execution phase**, if the model is kept up-to-date, this BIM use can support the **prime contractor** in adjusting orders to current demand for resources. Throughout the construction process, prime contractors, designers, subcontractors and suppliers can visualize both area and location of available space on site through this BIM use, which can be valuable for planning of logistics activities.

Figure 6. Excerpt from Appendix C.

In Appendix B, each of the 11 BIM uses for construction logistics are described, and explanations of how the BIM uses can support construction logistics optimization are given. An excerpt from Appendix B is given in the previous page (see Figure 6) to demonstrate how the 11 BIM uses could support construction logistics optimization. The 11 BIM uses for construction logistics chosen by the PDEng trainee will later be verified by BIM managers and BIM experts. Afterward, the resulting BIM uses for construction logistics will serve as input for the design of the BIM scenarios for construction logistics.

2.1.2. Review of literature and professional publications on incentives

A goal of the review was to identify possible incentives that can be applied to the use of BIM for construction logistics. Literature on incentives, behavior and rewards were reviewed to identify incentives used in the construction industry in general. In addition, professional publications were reviewed to identify incentives used in the construction industry in the Netherlands. The review resulted to 11 incentives, which are listed in Table **6**.

Table 6. List of incentives obtained from the review.

Incentives used in the construction industry	
1	Integrated contract model
2	Integrated supply chain
3	MEAT criteria
4	Require the use of BIM (pay for BIM activities)
5	Select organizations based on their competence and readiness
6	Past performance (prestatiemeten)
7	Adjusting the use of BIM according to the needs of involved organizations
8	Risk sharing
9	Sharing of savings
10	Bonus
11	Malus

Financial incentives can be categorized into incentives before contract formation (i.e. across projects and during initiation) and incentives during the realization of the task commissioned in the contract. Furthermore, the incentives obtained from the review can be divided into the 1st layer (client – prime contractor) and 2nd layer (prime contractor – designer, subcontractor and supplier) relationships. Table **7** lists the incentives according to their category.

Table 7. Categorization of incentives.

<table>
<tr><th></th><th>Across projects</th><th>During initiation</th><th>During contract realization</th></tr>
<tr><td rowspan="2">1st layer relationship</td><td rowspan="2">Past performance</td><td>Integrated contract model</td><td rowspan="2"></td></tr>
<tr><td>MEAT criteria</td></tr>
<tr><td>2nd layer relationship</td><td>Integrated supply chain</td><td></td><td></td></tr>
<tr><td rowspan="5">Both layers</td><td rowspan="5">Select organizations based on their competence and readiness</td><td rowspan="5">Adjusting the use of BIM according to the needs of involved organizations</td><td>Require the use of BIM (pay for BIM activities)</td></tr>
<tr><td>Risk sharing</td></tr>
<tr><td>Sharing of savings</td></tr>
<tr><td>Bonus</td></tr>
<tr><td>Malus</td></tr>
</table>

The descriptions of the incentives and how they can be applied to BIM uses for construction logistics will be described next.

1st layer relationship

Past performance – also known in Dutch as prestatiemeten, is a system in which the performance (how the prime contractor or designer fulfilled his contractual obligations) of the prime contractor or designer is measured and scored. The resulting scores will be included in the selection of the prime contractor or designer of the next tender. A high score will result to an equivalent fictional reduction on the bid price. This creates an incentive for the prime contractor or designer to perform well in the current project and to behave cooperatively, for which the prime contractor or designer gains a better chance of future work (PIANOo, 2014b).

Integrated contract model – In integrated contract models, the prime contractor is responsible for design and execution (and possibly finance, maintenance and operation). The prime contractor has the opportunity to and benefits from optimizing design and execution, and construction logistics. Furthermore, the prime contractor has the opportunity to align processes and ICT among organizations (Glick & Guggemos, 2009). Since BIM supports the optimization of design and execution (Eastman et al., 2011; Sacks, Akinci, & Ergen, 2003) and the optimization of construction logistics (Hartmann & Fischer, 2007; Hartmann, Gao, & Fischer, 2008; Trebbe et al., 2015; Zanen et al., 2013), then the prime contractor is incentivized to apply BIM uses for construction logistics in construction projects with an integrated contract model.

MEAT criteria – The MEAT (most economically advantageous tender) criteria are a set of criteria used to compare bids and to determine the winning bid. Instead of comparing the bids on the basis of lowest price alone, bids are compared on the basis of both quality and price. The use of the MEAT criteria can increase the motivation of the prime contractor to think of the objectives of the client, with the reward of a better chance of being awarded the contract (PIANOo, 2014a). MEAT criteria related to BIM and construction logistics can be created and applied in a construction project to motivate prime contractors to apply BIM uses and optimize construction logistics. The weight (percentage) of the MEAT criteria related to BIM and logistics should be large enough to motivate candidates to address the MEAT criteria. In other words, candidates weigh the costs of the strategies or measures against the amount of points that can be won for these strategies or measures. If the MEAT criterion has a large percentage (heavy weight), then candidates are more likely to develop strategies or measures that address these criteria. However, the percentages of each MEAT criterion depend on the project goals.

2nd layer relationship

Integrated supply chain – In integrated supply chains, there is either deliberate or strategic repetition between projects. The prime contractor and its partners (designers, subcontractors and suppliers) have long-term relationships and make use of advanced compensation structures, such as risk and sharing of savings (Vrijhoef, 2011). These organizations have the opportunity to and can benefit from applying advanced planning and logistics strategies, such as just-in-time production and delivery, and prefabrication (Vrijhoef, 2011). BIM uses for construction logistics can support the application of these strategies. Furthermore, these organizations have the opportunity to and can benefit from aligning and sharing information standards and ICT, such as BIM. Therefore, these organizations are incentivized to apply BIM uses for construction logistics in their projects.

Both layers

Select organizations based on their competence and readiness – During (pre)selection, prime contractors, designers, subcontractors and suppliers undergo a qualification process where they are screened for suitability, through several criteria regarding their financial and economic capacity, and their technical and professional competence (PIANOo, n.d.). A criterion on the organization's BIM competence and readiness can be included as one of the suitability criteria. Organizations who satisfy these criteria will be invited to bid, while those who fail to satisfy will be excluded from the bidding. This creates an incentive for the organization to invest in and develop its BIM competencies.

Adjusting the use of BIM according to the needs of involved organizations – The use of BIM and/or the BIM data required to be delivered by organizations can be adjusted to be more suited to the needs of other organizations participating in the use of BIM (Eastman et al., 2011; Glick & Guggemos, 2009). This creates an incentive for the prime contractor, designer, subcontractor or supplier to deliver BIM data required by other project partners in exchange for BIM data required by its own organization, instead of being paid (extra) for the (extra) BIM activities.

Require the use of BIM (pay for BIM activities) – BIM uses for construction logistics can be required from the beginning of the contract, or after the contract is awarded, in which case, the requirement will form a change in scope. When BIM uses for construction logistics are requested (and paid for) by the client or the prime contractor, then the supplying organization is externally motivated to apply BIM uses for construction logistics in the project.

Risk sharing – Organizations can be motivated to proactively manage a risk if they benefit when the risk does not occur. This benefit can be created when the responsibility for a risk is shared. When risks are shared, organizations are motivated to share information, improve communication, collaborate and commit to agreements to reduce the risks (Chao-Duivis, Koning, & Ubink, 2010; RRBouw, 2004). BIM can aid in sharing information, improving communication, and enhancing collaboration among organizations involved in a construction project. This creates an incentive for clients, prime contractors, designers, subcontractors and suppliers to use BIM.

Preconditions of risk sharing are transparency and trust from both parties. Parties should also have the financial capacity to carry the allotted risks. In addition, both parties have to contribute to the shared risk funds and both parties should be able to control the risk. That is, risks that can be influenced only by one party are not shared and the costs of their occurrence are not covered by the shared risk fund. This differs from collaborative contract models, such as alliances, in which all risks, profits and losses are shared among the parties. Alliances provide a very suitable basis for sharing risks, since they provide a judicial framework from which parties can model their contract. In addition, alliances allow for the early and close involvement of parties (i.e. involvement during the design phase and ability to influence the design), which is necessary for parties to control or reduce the risks (RRBouw, 2004).

Sharing of savings – When organizations perform better (save costs) through BIM, the savings can be shared among the involved organizations according to a predetermined percentage of distribution. Through this, organizations are motivated to perform better together (using BIM) (Chao-Duivis et al., 2010). Sharing of savings requires transparency and trust among the organizations involved. The organizations have to be transparent in the costs and savings they (will) incur, and they have to trust each other that these costs and savings are accurate.

Bonus – A bonus can be coupled to the correct and ahead of time or on time delivery of BIM data. This creates the incentive for the prime contractor, designer, subcontractor or supplier to (continuously) deliver BIM data according to agreements. A bonus can also be coupled to the delivery of extra BIM data. This creates the incentive for the prime contractor, designer, subcontractor or supplier to exert extra effort without increasing the contract price.

When awarding bonuses, clients or prime contractors should be careful that they're not motivating undesired behavior. For example, bonuses can have the effect that the receiving organization focuses on delivering ahead of time to receive the bonus and ends up compromising the quality. In addition, bonuses should be coupled to indicators, which are observable, measurable, verifiable, and feasible (Jaraiedi, Plummer, & Aber, 1995). On the other hand, receiving organizations consider the costs associated with delivering ahead of time against the bonus they will receive for it. If the difference is not significant for the receiving organization, then the bonus will not be effective in motivating the receiving organization to behave in the manner desired by the awarding organization (Jaraiedi et al., 1995).

Malus – During contract formulation, parties can stipulate in their contract to couple a malus with the incorrect and/or late delivery of BIM data. This creates an incentive for the receiving organization to (continuously) deliver BIM data according to agreements (Jaraiedi et al., 1995).

The list of possible incentives will be appended by contract managers (subsection 2.2.2). Afterward, they will be further developed for the use of BIM for construction logistics in Chapter 3. It is important that the developed incentives are anchored to the contract that organizations enter into with each other, for example, through the BIM protocol. In the next subsection, it will be discussed which agreements should be added in existing BIM protocols to anchor BIM uses for construction logistics and related incentives in the contract.

2.1.3. Review of existing BIM protocols

Objectives of the review were to identify common agreements included in existing BIM protocols in the construction industry in the Netherlands and to determine which agreements should be added for the application of BIM uses for construction logistics. The Building Information Council of the Netherlands advocates for a naming convention across the whole industry. The council proposed that the term 'BIM Protocol' should refer to the document containing BIM-related agreements between the client and the prime contractor, while the term 'BIM Execution Plan' should refer to the document containing BIM-related agreements between the prime contractor, designers, subcontractors and suppliers.

In this PDEng project, both the BIM Protocol and the BIM Execution Plan were considered. Table **8** lists the BIM protocols that were reviewed.

Table 8. Overview of reviewed BIM protocols.

BIM protocols from practice	
1	Building Information Council – National BIM Protocol Release 0.9 (2017)
2	Building Information Council – National BIM Execution Plan Release 1.0 (2017)
3	BIM protocol provided by a prime contractor (2015)
4	BIM protocol for design provided by a consulting firm (2015)
5	BIM protocol provided by a prime contractor (2015)
6	BIM execution plan provided by a prime contractor (2014)
7	BIM protocol provided by a prime contractor (2013)
8	BIM execution plan provided by a subcontractor (no date)

Table **9** gives an overview of the agreements included in each of the eight BIM protocols reviewed. Agreements regarding definitions are common to all of the existing BIM protocols included in this review. These agreements contain the definitions agreed upon by the participating organizations. These include the definitions for Level-Of-Development (LOD) that are considered in the project, the standards that are applicable to the project, and the definitions of the BIM-related roles.

According to the Building Information Council of the Netherlands, agreements on the delivery scheme is the most important part of the BIM Protocol. The delivery scheme stipulates which information should be delivered to which organization, by which organization, in which Level-Of-Development (LOD), at which time, and in which format (see Table **10**). The delivery scheme should be in accordance with the

Information Delivery Scheme (Informatie Leverings Specificatie or ILS in Dutch), which is agreed upon by the client and the prime contractor. Each project partner/ project discipline should indicate which information he/she needs (in which LOD and when), in order to fulfil the information requirements of the client, as specified in the ILS.

Table 9. Overview of agreements included in the eight BIM protocols reviewed.

Agreement	Reviewed BIM protocol							
	1	2	3	4	5	6	7	8
Definitions	☑	☑	☑	☑	☑	☑	☑	☑
Roles and responsibilities of participating organizations	☑	☑			☑	☑	☑	
Hierarchy of contract documents	☑							
Intellectual property rights and ownership of the model	☑							
Liabilities for BIM data	☑							
Delivery scheme	☑	☑						
Project details		☑		☑			☑	
BIM organization scheme		☑			☑	☑	☑	☑
Data exchange standards and file formats		☑	☑	☑	☑	☑		☑
BIM goals and BIM uses		☑		☑			☑	
Modeling agreements		☑	☑	☑	☑			
Model management		☑	☑	☑	☑	☑	☑	

Table 10. Example of a delivery scheme (BIR Werkgroup BIM Protocol, 2016b, p. 27).

Information/ Data	Requesting organization	Delivering organization	LOD	Date	Format

A delivery scheme is also important when applying BIM uses for construction logistics. When organizations fill-in a delivery scheme specifically for applying BIM uses for construction logistics, they become aware of both their own and of other organization's logistics requirements. By agreeing upon a delivery scheme, organizations are held accountable for the correct and timely delivery of information throughout the construction process.

However, most of the BIM protocols included in this review did not contain a delivery scheme. There were also no agreements regarding logistics-related BIM data included in the existing BIM protocols included in this review. For the successful application of the BIM uses for construction logistics in a project, a delivery scheme for the logistics-related BIM data should be included in the BIM protocol.

Furthermore, most of the BIM protocols included in this review did not contain agreements regarding BIM goals and BIM uses. It is important to clearly define and agree upon the goals for using BIM in the project as early as possible, as the goals partially define the intended content of BIM for each phase of the construction project. Therefore, defining and agreeing upon the BIM uses for construction logistics as early as possible is also important for successfully applying BIM uses for construction logistics in a project.

Incentives linked to BIM (and its benefits) are currently seldom applied in practice. None of the existing BIM protocols included in this review contained agreements regarding incentives. When incentives for applying BIM uses for construction logistics are available, the BIM protocol can play an important role in keeping (an) organization(s) to the terms of the incentives. Therefore, agreements regarding the incentives linked to BIM uses for construction logistics should be added to existing BIM protocols.

In summary, for the application of BIM uses for construction logistics, existing BIM protocols should be appended with:

1) Agreements regarding the logistics-related BIM data exchange, containing:
    a) Which BIM uses for construction logistics will be applied in the project
    b) Which logistics-related information should be delivered (to and by which organization) when, and in which LOD and format.
2) Agreements regarding the incentives linked to BIM uses for construction logistics and their benefits.

2.2 INTERVIEWS

In this section, the results of the second step of the problem investigation phase will be discussed. The results of the interviews with BIM managers and experts will first be presented (subsection 2.2.1), followed by the results of the interviews with contract managers (subsection 2.2.2). The objectives of the interviews, as discussed in subsection 1.2.2, are listed in Table 11.

Table 11. Objectives of the interviews.

	Product 1. BIM scenarios for construction logistics	Product 2. Incentives for applying BIM uses for construction logistics
Step 2. Interviews	-Validate (and append) the list of BIM uses, and their potential benefits for construction logistics obtained from step 1	-Validate (and append) the list of incentives obtained from step 1

2.2.1. Interviews with BIM managers and experts

The list of BIM uses for construction logistics compiled from literature (Table 5) was checked for completeness by conducting interviews with BIM managers and BIM experts. First, the list of BIM uses for construction logistics from literature was discussed with the trainee's supervisor, a BIM expert. This resulted to two additional BIM uses for construction logistics:

1) Coupling of BIM with traffic simulation models
2) Optimizing logistics for multiple projects within the same region

The descriptions of the above two BIM uses can be found in Appendix C. Second, interviews with BIM managers were conducted in 2015 in relation to a group assignment for the MSc subject: Supply Chain Management & ICT. The interviewees were asked to specify which of the BIM uses were used to support construction logistics optimization. This resulted to the 13 BIM uses for construction logistics listed in Table 12.

Table 12. List of BIM uses for construction logistics, validated by BIM managers and BIM experts.

BIM uses for construction logistics	
1	Data exchange with other project partners/project disciplines
2	Generating quantities from the 3D model
3	Coupling of 3D model to a planning (4D modeling)
4	Cost estimation with the 3D model (5D modeling)
5	Labelling and numbering of objects for production, installation and logistics
6	Positioning via laser and machine guidance techniques
7	3D coordination (management of subcontractors and suppliers)
8	Support of lean sessions with the model
9	Monitoring of logistics via RFID-tags and/or barcodes
10	3D modeling of temporary structures
11	Coupling of BIM with GIS
12	Coupling of BIM with traffic simulation models
13	Optimizing logistics for multiple projects within the same region

The most common benefits of using BIM perceived by the interviewees were reduction of failure costs during execution through the minimization of clashes in the design, and an improved communication with project partners through the visualization of the design. BIM was used by prime contractors more during the design phases than during the execution or operation and maintenance phases. However, when prime contractors have an integrated supply chain with subcontractors and suppliers, then subcontractors and suppliers participated in the use of BIM during the design phases. Subcontractors and suppliers were responsible for developing BIM models during the technical design phase.

At the time of the interviews (October-December 2015), BIM uses for construction logistics were scarcely applied by the organizations of the interviewees. BIM uses for construction logistics most commonly applied in practice were Generating quantities from the 3D model and Support during lean sessions. Other BIM uses for construction logistics currently applied in practice, although rarely and not yet specific for construction logistics, were Data exchange with other project partners/ project disciplines, and Coupling of 3D model to a planning (4D modeling). Use of BIM for construction logistics by subcontractors and suppliers is still limited. The interviewed subcontractor did not perceive the use of BIM for construction logistics as beneficial. The subcontractor only used BIM if it was required by the prime contractor and thought that it was too costly to use.

The other BIM uses for construction logistics, which are not being applied yet in practice, were currently perceived to be too advanced to be applied in practice. For feasibility, the BIM scenarios for construction logistics will be chosen among the four BIM uses for construction logistics that are already applied in practice, although rarely and not yet specific for construction logistics.

2.2.2. Interviews with contract managers

The list of incentives used in the construction industry obtained from the review (Table 6) were then checked for completeness by contract managers and purchasing managers (see Appendix I for list of interviewees). The interviewees added two incentives to the list of incentives obtained from literature. This resulted to 13 incentives obtained from steps 1 and 2, listed in Table 13.

1) Step-in possibility – the possibility for the prime contractor to intervene with the activities of the designer, subcontractor or supplier in case the latter party appears to lag behind the schedule. This creates an incentive for the designer, subcontractor or supplier to setup his processes in a way that would ensure correct and timely delivery of BIM data.
2) Payments coupled to deliveries – during contract formulation, the parties can set and agree upon a number of payment terms, which are periods when payments are due to the prime contractor, designer, subcontractor or supplier. Often, the parties also agree upon which activities should be completed within each set of payment.
   Therefore, to receive payment, the prime contractor, designer, subcontractor or supplier has to accomplish these activities on time and to provide proof of their accomplishment. This creates an incentive for an organization to plan and execute activities smoothly. Since BIM uses for construction logistics reduce errors and shorten lead times, organizations are incentivized to apply BIM uses for construction logistics in the project. Furthermore, payments can be coupled to the correct delivery of BIM data. This creates an incentive for organizations to deliver BIM data correctly and timely.

The interviewees expressed that creating MEAT criteria directly about the use of BIM is not desirable. BIM is not the goal, therefore, it is not desirable to directly award points for the use of BIM alone. However, the **interviewees perceived that the MEAT criteria can be an effective and feasible incentive to motivate prime contractors to apply BIM uses for construction logistics in a project**. Clients often pose a problem or an objective to the market, and ask candidates to offer solutions or measures to this problem or objective. These solutions or measures should be made clear or understood by the client, to allow the client to evaluate whether these solutions or measures lead to the desired effect or goal. Therefore, if the solutions or measures are S.M.A.R.T.-ly formulated and if the candidate is more able to prove or indicate the effects of these solutions or measures, then the candidate can score higher for that MEAT criterion. The use of BIM can greatly aid in proving and indicating the effects of the proposed solutions. Therefore, an incentive arises for the prime contractor to apply BIM uses for construction logistics.

Table 13. Validated list of incentives from steps 1 and 2 of the problem investigation phase.

Validated list of incentives	
1	Integrated contract model
2	Integrated supply chain
3	MEAT criteria
4	Require the use of BIM (pay for BIM activities)
5	Select organizations based on their competence and readiness
6	Past performance (prestatiemeten)
7	Adjusting the use of BIM according to the needs of involved organizations
8	Risk sharing
9	Sharing of savings
10	Bonus
11	Malus
12	Step-in possibility
13	Payments coupled to deliveries

Currently, requiring the use of BIM (paying for BIM activities) was the most commonly applied incentive for BIM, according to the interviewees. The interviewees have not encountered other incentives directed towards applying BIM uses for construction logistics in practice. Incentives play a critical role in economic decision making (Chang & Howard, 2016), and can influence an organization's intention to apply BIM uses for construction logistics (in the intended way) in a project. Therefore, there is a need to create incentives for applying BIM uses for construction logistics.

According to all the interviewees, the most important incentive is for the organization to perceive the benefits of BIM. In addition, all the interviewees expressed that an integrated contract model is an important precondition for this incentive. Integrated contract models provide the possibility for the prime contractor to start using BIM during the design phase, which maximizes the benefits of BIM. Next to the benefits of BIM, the most important incentives for each layer relationship will be given below.

1st layer relationship - Risk sharing and sharing of savings are viewed as the most important incentives next to the benefits of BIM. In addition, since BIM can aid in minimizing risks and in reducing costs, prime contractors are then also motivated to apply BIM by the incentive of risk sharing and sharing of savings. **2nd layer relationship** - Selecting organizations based on their BIM competence and readiness is seen as the most important incentive next to the benefits of BIM. This incentive provides a chance for the designers, subcontractors and suppliers to earn back the investments related to BIM, and to be ahead of competition.

For motivating organizations to (continuously) deliver BIM data on time, one of the interviewees stated that coupling of payments to deliveries is the most effective. On the other hand, the bonus and malus are seen as least effective. Organizations are seldom motivated by bonuses, since organizations always include a margin of profit in their prices. On the other hand, maluses are perceived as one-sided and not aligned with the spirit of collaboration. In addition, it is very tricky to determine when (not) to award the bonus or malus because an argument often arises about whether or not the awarding criteria were (not) met. A bonus or malus is also given too late. For example, when the designer, subcontractor or supplier delivers too late, the prime contractor's own construction process will be disturbed. Instead, coupling of payments to deliveries and the step-in possibility are preferred over a bonus or malus.

2.3 CASE STUDY

In this section, the results of the third step in the problem investigation phase will be discussed. This section is structured into subsections that correspond to the products of the PDEng project. Subsections 2.3.1 and 2.3.2 contain the results of the case study with regards to the BIM scenarios for construction logistics and incentives for applying BIM uses for construction logistics, respectively.

The objectives of the case study for each of the design products are listed in Table **14**.

Table 14. Objectives of the case study.

	Product 1. BIM scenarios for construction logistics	Product 2. Incentives for applying BIM uses for construction logistics
Step 3. Case study	-Validate (and append) the logistics requirements of organizations -Investigate why organizations chose (not) to apply BIM uses for construction logistics (in the intended way), specifically the benefits (and disadvantages) of the BIM uses for construction logistics perceived by each organization	-Investigate how organizations can be motivated to apply BIM uses for construction logistics in the intended way

Two construction projects were included in the case study. Table **15** gives an overview of the two construction projects.

Table 15. Overview of the case study.

	Boekelo Bridge Hengelo	N31 Highway Harlingen
Project type	Infrastructure project	Infrastructure project
Project phases studied	Design phase	Construction phase
Relationships studied	1st layer	1st and 2nd layers
Contract model	Design and Construct	Design and Construct
Awarding method	MEAT criteria	MEAT criteria
Project duration	August 2017 – January 2019	March 2014 – December 2017
Project budget	€ 8 million	€ 146 million

More detailed descriptions of Boekelo Bride Hengelo and N31 Highway Harlingen can be found in Appendix D and Appendix E, respectively.

2.3.1. Results regarding the BIM scenarios for construction logistics

An objective of the case study was to investigate why organizations choose (not) to apply BIM uses for construction logistics. Focus was given on validating and appending the logistics requirements of the organizations, and the benefits (and disadvantages) of BIM uses for construction logistics perceived by organizations, which influence an organization's intention to apply BIM uses for construction logistics.

From the case study, reasons for choosing to both apply and not apply BIM uses for construction logistics were found. Before explaining the reasons for (not) applying BIM uses for construction logistics, the logistics requirements of organizations in the projects will first be described. Based on the logistics requirements found in the projects, the PDEng trainee suggested specific BIM uses for construction logistics. The reasons of each organization for choosing to (not) apply these specific BIM uses for construction logistics will then be explained.

Boekelo Bridge Hengelo

In this project, the client has an interest in ensuring that the bridge is realized within the subsidy period. The client also values that there is little nuisance to the environment during the realization of the bridge. The project is in an industrial area and the bridge crosses the Twente Canal. The client evaluated that there are enough alternative routes for the road traffic around the Boekelo Bridge. Two bridges parallel to the Boekelo Bridge could serve as alternatives for the traffic passing Boekelo Bridge. The client also evaluated that there will be minimal nuisance to the waterway traffic during the replacement of the bridge.

Based on the above reasons, the client decided to close the bridge and redirect all road traffic away from the bridge for the whole construction period. To minimize the duration that the bridge will be unavailable to road traffic, the client decided to stimulate the prime contractor to reduce the duration of the construction period. This was achieved through the MEAT criterion for construction duration.

For this MEAT criterion, the prime contractor was asked to indicate the number of calendar months that they would like to deliver the work earlier than the delivery date of 01 June 2019. The prime contractor had the choice between one calendar month up to and including five calendar months earlier, in which one calendar month equals a certain amount of fictional price reduction. The prime contractor proposed to deliver the work five calendar months earlier, on 01 January 2019.

Logistics requirements

The logistics requirements of the prime contractor in this project are similar to the logistics requirements found in the literature review (Table **4** in subsection 2.1.1). The logistics requirements found in this project, which were also found in the literature review, are listed in Table **16**. Afterward, each of the logistics requirements found in this project will be explained.

Table 16. Logistics requirements of the prime contractor of the Boekelo Bridge Hengelo.

	Logistics requirements	
Tender-Design phase (FOR INTEGRATED CONTRACTS)	Prime contractor	• Optimize construction method and construction sequence, and eventually optimize design • Align designs from various disciplines, which results to less design errors and consequently, less disruptions to the execution and logistics process. • Consistently process design changes in all drawings, which results to less errors in drawings and consequently, less disruptions to the execution and logistics process.

To reduce the duration of construction, the prime contractor needs to optimize the logistics related to the assembly of the bridge. For this, the prime contractor had to optimize the design of bridge components and their installation sequence. The bridge had to be divided into components such that they could be easily installed. Furthermore, the of assembly of the bridge should be planned such that it could be installed in the quickest way. The prime contractor desired to simulate the shipping of the bridge to the site and its assembly on site. To simulate the shipping and assembly of the bridge, the prime contractor applied Coupling of 3D model to a planning (4D modeling) during the design phase.

Another logistics requirement of the prime contractor was to ensure that the project would be completed on the proposed date, to prevent incurring penalties. For this, the prime contractor aimed for a smooth execution of construction operations by preventing errors from occurring during execution on site. The prime contractor desired to eliminate/reduce clashes in the design, and to ensure that the joints between bridge components fit perfectly. To prevent errors from occurring during the execution phase, the prime contractor applied Data exchange with other project partners/ project disciplines during the design phase.

Reasons for choosing to apply BIM use for construction logistics – case of Boekelo Bridge Hengelo

Although construction logistics was not a critical issue in this project, the prime contractor still chose to apply BIM uses for construction logistics. The prime contractor in this project is among the top ten largest prime contractors in the Netherlands. The company's strategy is to use BIM in all its projects by 2018. By itself, the benefits of BIM uses for construction logistics incentivized the prime contractor to apply them in this project.

The aesthetic quality of the bridge was the most important criterion for the client during the tender phase. The primary goal of the prime contractor in using BIM in this project was not for optimizing construction logistics, but for modeling existing conditions and visualizing the new bridge in these conditions to demonstrate the aesthetic quality of the bridge design to the client using the model. For this goal, the prime contractor created a 3D model of the bridge in the existing conditions.

Since the prime contractor would create a 3D model of the bridge, the prime contractor could make use of the 3D model for other BIM goals and BIM uses. During the tender phase, the prime contractor considered BIM goals and BIM uses that would be beneficial for this project, based on his needs. As mentioned above, the logistics requirements that the prime contractor recognized were:

1) Optimal assembly of the bridge for shorter construction duration
2) Smooth execution of construction operations for timely completion of the project

The prime contractor perceived that BIM uses for construction logistics could address these needs – in other words, perceived the benefits of BIM uses for construction logistics – and chose to apply them. As mentioned above, the prime contractor applied two BIM uses for construction logistics: 1) Coupling of a 3D model to a planning, and 2) Data exchange with other project partners/ project disciplines. More importantly, the prime contractor not only perceived their benefits, but also had the necessary knowledge and skills to apply them.

N31 Highway Harlingen

Construction logistics was an important aspect in this project. N31 is a national highway with important connections to the underlying road network and bicycle lanes, and an intersection with a local rail. Nuisance to the users of the highway, underlying road network and bicycle lanes must be kept at a minimum. In addition, access to the businesses, schools and hospital during the construction phase must be maximized.

To minimize nuisance to the public, the client applied a MEAT criterion for minimizing nuisance. The MEAT criteria was composed of six evaluation aspects, listed in Table 17.

Table 17. Nuisance evaluation aspects.

Category	Nuisance evaluation aspects
Nuisance to road traffic	Number of weekends used for conducting construction works
	Number of nights used for conducting construction works
Nuisance to the surrounding environment	Accessibility, livability, safety and communication during the construction phase
	Extent of use of the underlying road network by construction related traffic
	Prevention of nuisance and damage [out of scope: not related to logistics]
	Prevention of complaints [out of scope]

For the MEAT criterion Minimize nuisance, during the tender phase, the prime contractor proposed to implement the following strategies (Table 18):

Table 18. Nuisance mitigation strategies proposed by the prime contractor.

Nuisance evaluation aspects	Nuisance mitigation strategies
Number of weekends used for conducting construction works	[Confidential]
Number of nights used for conducting construction works	[Confidential]
Accessibility, livability, safety and communication during the construction phase	The prime contractor proposed to maintain all existing roads and bicycle lanes. To minimize the nuisance to the users of the highway caused by construction traffic, the prime contractor proposed to build an overpass to separate the construction traffic from the public.
Extent of use of the underlying road network by construction related traffic	The prime contractor proposed to avoid the use of the underlying road network for construction related traffic. Instead, construction traffic would make use of the N31 highway, and of its own temporary roads.

Logistics requirements

In this project, similar logistics requirements to the logistics requirements from the literature review (Table **4** in subsection 2.1.1) were found. Also, there were additional logistics requirements found in this project. Table **19** lists all of the logistics requirements found in this project. The additional logistics requirements are listed in ***bold and italics***. Afterward, each of the logistics requirements found in this project will be explained.

Table 19. Logistics requirements of organizations in N31 Highway Harlingen.

	Logistics requirements	
Tender-Design phase (FOR INTEGRATED CONTRACTS)	Client	• Visualize the effects of alternative construction phase planning ***and risk mitigation strategies*** on traffic flows and the availability of public and temporary roads.
	Prime contractor	• Efficiently analyze and compare effects of alternative construction phase planning ***and risk mitigation strategies*** on traffic flows and the availability of public and temporary roads. • Optimize construction method and construction sequence, and eventually optimize design
	Designer	• Align designs from various disciplines, which results to less design errors and consequently, less disruptions to the execution and logistics process. • Consistently process design changes in all drawings, which results to less errors in drawings and consequently, less disruptions to the execution and logistics process.
Project engineering phase	Prime contractor	• ***Independently navigate through the design from each possible perspective and at various moments during the construction process to gain insight into the conditions for execution.***
Execution phase	Prime contractor	• Align on a detailed level which party is working where and when. • Optimize use of space on site.
	Subcontractors and suppliers	• Determine what, when and how much should be delivered, and eventually optimize delivery options

During the execution phase, it was found that the nuisance mitigation strategies proposed by the prime contractor for the MEAT criterion Minimize Nuisance resulted to long distances travelled by the trucks. Since the trucks were not allowed to use the underlying road networks, trucks often had to traverse sections of the main highway four times longer to get to and from the location of activities when transporting resources. The long distances travelled by the trucks resulted to longer transportation durations of resources to and out of the location of activities. This lowered the productivity rate of the subcontractors, which led to delays in completion of activities. Furthermore, the long distances also resulted to increased CO_2 emissions and traffic congestion on the main highway.

To develop more effective mitigation strategies in future projects, the prime contractor needs to efficiently analyze and compare the effects of alternative construction phase planning and risk mitigation strategies on traffic flows and the availability of public and temporary roads during the tender and design phase of the project. Furthermore, the prime contractor needs to optimize construction method and construction sequence, and eventually optimize design to reduce the effect of planned construction activities on traffic. Similarly, the client also needs to evaluate the effects of alternative construction phase planning and risk mitigation strategies on traffic flows and the availability of public and temporary roads.

Also during the execution phase, it was found that the estimated and planned duration to construct a portion of the highway was inadequate. The cramped space caused by the strut retaining walls lowered the productivity rate of the earthmoving subcontractor, leading to a longer duration in the completion of earthwork activities (draining, digging, and grading). For each portion of the highway, the tasks of draining, digging, placing of retaining walls, grading, placing of formworks, placing of reinforcement steel, concrete pouring, removing of formworks and paving had to be performed in sequence. The lower productivity rate of the earthwork activities delayed the rest of the activities and resulted to a longer duration for constructing one portion of the highway.

The prime contractor had to speed up the construction process by starting an additional stream of construction activities, and by working on weekends and at night to avoid incurring penalties for delayed project turnover. However, even these measures did not prevent a delay in project turnover, and the prime contractor had to pay penalties, in addition to the extra costs incurred for the measures.

To reduce the risk of delay of project completion, the designers should align designs from various disciplines and consistently process design changes in all drawings, to minimize design errors and consequently, minimize disruptions to the execution and logistics process. Furthermore, a 4D simulation of the critical construction activities is needed to more accurately estimate their duration. The prime contractor should be able to independently navigate through the design from each possible perspective and at various moments during the construction process to gain insight into the conditions for execution.

Another bottleneck encountered during the execution phase was that the information provided by the subcontractors during the construction phase on the availability of materials and their equipment and space needs was incomplete. Subcontractors and suppliers should determine what, when and how much should be delivered, based on comprehensive and up-to-date information on the design and status of activities on site.

Incomplete information from the subcontractors and suppliers, combined with the fact that the prime contractor also had no access to comprehensive information on materials and equipment availability from subcontractors in the critical path, was another major bottleneck in the project. The lack of information resulted to lack of available space on site and idle times for subcontractors and suppliers, thereby increasing the cost and duration of activities. These information is needed by the prime contractor to align on a detailed level which party is working where and when, and to optimize use of space on site.

Possible BIM scenarios and their benefits
For the development of more effective nuisance mitigation strategies, the prime contractor could implement the BIM scenario: 'Coupling of BIM with traffic simulation models', which is a process in which the model is linked to traffic simulation software to visualize and analyze the effects of (planned) construction activities on traffic, for example, the effects on traveling time through construction area, traffic congestion, and traffic safety.

The prime contractors can then use the traffic models to analyze and optimize the effects of different alternatives of their planning and traffic measures on road traffic. The quantities of material for each construction phase of their alternative plans can be exported from the 4D model to a spreadsheet. By dividing the quantities by the capacity of the chosen means of transport, the number of construction traffic flows can be determined and entered into the traffic model. By means of the traffic model, the prime contractors can adjust the mitigation measures to prevent undesirable consequences, such as longer transportation routes and larger CO_2 emissions, from occurring.

Coupling of 3D model to a planning (4D modeling) during the design phase could have supported the prime contractor in more accurately estimating the duration of activities. A simulation of the sequential tasks of draining, digging, grading, placing of formworks, placing of reinforcement steel, concrete pouring, removing of formworks and paving would provide the prime contractor with insight into possible complexities. Since the duration of these tasks greatly influenced the overall duration of the construction project, the prime contractor would have greatly benefited from timely and accurately estimating their durations, to timely formulate and implement measures that are necessary to realize the project within the deadline.

To create visibility of (site) inventories, the prime contractor could monitor logistics via RFID-tags and/or barcodes. The BIM scenario: 'Monitoring of logistics via RFID-tags and/or barcodes', is a process in which the model is coupled to radio frequency identification (RFID) or wireless sensor networks (WSNs) to automatically collect and share information regarding the material and component flow throughout manufacturing, shipping, delivery and erecting processes. BIM components linked to RFID-tags can automatically update work status and provide rapid feedback on field progress and installation.

This BIM scenario would benefit the prime contractor, subcontractors and suppliers by creating visibility to (site) inventories, which include reliable information on material availability and location on site or elsewhere along the supply chain. This technology has not yet been widely implemented in practice and can still be costly to implement. Further research is needed to investigate its use in practice, and to gain insight into the requirements for successfully implementing this technology.

Reasons for choosing not to apply BIM uses for construction logistics – case of N31 Highway Harlingen
As explained above, BIM uses for construction logistics could have benefits for the N31 Highway Harlingen project. However, there were no BIM uses for construction logistics applied in the project. By itself, the benefits of BIM uses for construction logistics were not sufficient to lead to their application in the project. The reasons found for each organization included in the case study will be explained below.

Prime contractor – Although the prime contractor perceived some of the benefits of BIM uses for construction logistics, this was by itself not sufficient for the prime contractor to invest resources to overcome barriers to the intended use of BIM. One of the main barriers to applying BIM uses for construction logistics in this project was the level of knowledge and skills of the employees with regards to BIM. This aspect, together with the level of effort required to implement BIM, impeded the implementation of BIM.

Furthermore, at the beginning of the project, the prime contractor perceived that the project was not complex enough to apply BIM. Other ICT, such as a shared database, were also not used in the project.

Practitioners in the project communicated and exchanged information through email correspondence, telephone and personal communication.

Designer – The main reason cited for not applying BIM uses for construction logistics was that it was not requested by the prime contractor. There were no external motivating factors present in the project. In addition, the designer expressed that the prime contractor had both the expertise and responsibility regarding construction logistics. Therefore, BIM uses for construction logistics were not perceived by the designer to be useful for executing his/her tasks.

Subcontractors and suppliers – First, although practitioners of the subcontractors and suppliers have received BIM training provided by the prime contractor, and the subcontractors and suppliers perceive benefits of BIM, their own organizations have not implemented BIM yet. Therefore, they did not have the necessary hardware and software to implement BIM in this project. This aspect, combined with the lack of external motivation, postponed the implementation of BIM by the subcontractors and suppliers.

Second, the time pressure experienced in the project was a barrier for the subcontractors and suppliers to implement BIM for the first time. The subcontractors and suppliers perceived a lack of time to learn and implement BIM in this project, and therefore, they opted to implement the ICT that they have used before.

Last, another reason of the subcontractors and suppliers for not applying BIM uses for construction logistics was that the prime contractor did not use BIM. There was no 3D model available for the subcontractors and suppliers to use or build upon.

2.3.2. Results regarding the incentives for applying BIM uses for construction logistics

An objective of the case study was to investigate how organizations could be motivated to apply BIM uses for construction logistics in the intended way. From the case study, possible incentives for motivating organizations to apply BIM uses for construction logistics were found. Table 20 gives an overview of the incentives that were present in Boekelo Bridge Hengelo and N31 Highway Harlingen.

Table 20. Overview of incentives present in the case studies.

Incentive	Incentive present?	
	Boekelo Bridge	N31 Highway
Integrated contract model	Yes	Yes
Integrated supply chain	Not investigated	Yes
MEAT criteria	Yes	Yes
Require the use of BIM (pay for BIM activities)	No	No
Select organizations based on their competence and readiness	No	No
Past performance (prestatiemeten)	No	No
Adjusting the use of BIM according to the needs of involved organizations	No	No
Risk sharing	No	No
Sharing of savings	No	No
Bonus	No	No
Malus	Yes	Yes
Step-in possibility	No	No
Payments coupled to deliveries	No	No
Were BIM uses for construction logistics applied in the project?	Yes	No

Although similar incentives were present in the two construction projects, BIM uses for construction logistics were only applied in one of the construction projects. The main reasons found for not applying BIM uses for construction logistics in the N31 Highway Harlingen project were the lack of BIM competencies of the prime contractor, subcontractors and suppliers, and the unavailability of 3D model of the project.

In the Boekelo Bridge Hengelo project, the benefits of BIM perceived by the prime contractor, by itself, motivated the prime contractor to use BIM in the project. Aside from the benefits of BIM uses for construction logistics, two additional incentives present in the project influenced the prime contractor's choice to apply BIM uses for construction logistics. First, the integrated contract model used in the project was an important incentive for applying BIM uses for construction logistics. The prime contractor expressed that, although BIM could still be useful in traditional Design-Bid-Build contract types, the benefits would be limited compared to the costs of implementing BIM. The prime contractor perceived the integrated contract as a crucial enabler of the benefits of BIM uses for construction logistics.

Second, the MEAT criterion on Innovation also positively influenced the prime contractor's choice to apply BIM uses for construction logistics indirectly. The client demanded the prime contractor to propose innovative product and/or process solutions in exchange for a higher chance of winning the tender (the prime contractor received fictional price reductions for each innovative solution). The prime contractor proposed BIM as a process innovation, specifically the use of Mixed Reality, which indicated that the MEAT criterion on Innovation motivated the prime contractor at the beginning of the project to create 3D BI model of the project. The prime contractor perceived that the 3D model would have added value by using it for other purposes (i.e. for BIM uses for construction logistics). The prime contractor also perceived less required investment to apply BIM uses for construction logistics because the 3D model would be available.

The MEAT criterion on Construction duration also positively influenced the prime contractor's choice to apply BIM uses for construction logistics. The client requested the prime contractor to shorten the duration of the construction project in exchange for a higher chance of winning the tender (the prime contractor received a fictional price reduction for each month deducted from the planned duration of the project). Due to the MEAT criterion on Construction duration, the prime contractor perceived the need to ensure that the project would be completed on time. The use of 4D modeling helped the prime contractor to optimize the assembly of the bridge. Data exchange with other project partners/ project disciplines supported the prime contractor in detecting errors before the work on site started, to ensure that logistics operations could be executed smoothly and on schedule.

On the other hand, in the N31 Highway Harlingen project, the MEAT criterion for minimizing nuisance to road traffic did not lead to the application of BIM uses for construction logistics by the prime contractor. The client requested the prime contractor to propose strategies to mitigate the nuisance to the road traffic and the surrounding environment. The client evaluated the proposed strategies based on commitments of the prime contractor to avoid the use of the underlying road network, among others (for the complete evaluation criteria, see Table 36). In this case, the client relied on penalties to motivate the prime contractor to follow through on its commitments.

However, penalties are awarded in retrospect; the penalty is given when the prime contractor has already failed to follow through on its commitment. This incentive becomes less effective when the actor in charge of formulating the risk mitigation strategies is not the actor who will be responsible for the execution of the strategies and for ensuring that these strategies lead to the desired outcome. In this project, the actor that formulated the risk mitigation strategy was an external consultant hired during the tender phase, who was not involved during the execution phase of the project. During the execution phase, it was found that the risk mitigation strategies led to congestion in the main highway – resulting to higher CO_2 emissions – and to lower productivity rates of subcontractors – resulting to delays.

Instead, it is more effective when the evaluation criteria/ awarding criteria attach importance to demonstrating hard, concrete commitments that provide the client with certainty and to define measures with corresponding effects S.M.A.R.T.-ly. In this way, the prime contractor will be motivated to test the effectiveness of risk mitigation strategies before committing to them, and to demonstrate to the client at the beginning of the project how the proposed risk mitigation strategies will lead to the desired outcome.

2.4 CONCLUSIONS ON THE PROBLEM INVESTIGATION

In this section, the conclusions of the problem investigation phase will be discussed. This section is structured into subsections that correspond to the three products of the PDEng project. In subsections 2.4.1, 2.4.2, and 2.4.3, the outputs of this phase for design products 1, 2 and 3 will be discussed, respectively.

The main objectives of the problem investigation phase were to investigate why organizations choose (not) to use BIM (in the intended way) for construction logistics, and how organizations can be motivated to use BIM for construction logistics in the intended way. Table **21** lists the outputs of this phase for each of the design products.

Table 21. Outputs of the problem investigation phase.

	Product 1. BIM scenarios for construction logistics	Product 2. Incentives for applying BIM uses for construction logistics	Product 3. Addendum to the BIM protocol
Outputs of this phase	-Logistics requirements of organizations -Reasons for choosing (not) to apply BIM uses for construction logistics, specifically the benefits (and disadvantages) of BIM uses for construction logistics perceived by each organization	-Possible incentives for applying BIM uses for construction logistics, and how these incentives can be applied to motivate organizations to apply BIM uses for construction logistics in the intended way	-Agreements that must be added to existing BIM protocols

2.4.1. Product 1: BIM scenarios for construction logistics

In this phase, logistics requirements of each organization in various collaboration settings were determined. Organizations may have additional logistics requirements in projects with integrated contracts above the general logistics requirements in projects with traditional contracts. The logistics requirements in the tender-design phase are present in projects with integrated contracts, such as Design-Build.

BIM can be used in all phases of the construction project by various organizations to address the logistics requirements of organizations. There are 13 BIM uses found to support construction logistics optimization. The most common benefits of BIM uses for construction logistics were reduction of failure costs during execution through the minimization of clashes in the design, and an improved communication with project partners through the visualization of the design.

Although there are 13 BIM uses that support construction logistics optimization, most of the 13 BIM uses for construction logistics were not yet applied in practice by the organizations that were interviewed and included in the study. Currently, these organizations rarely make the link between BIM and construction logistics. Among the 13 BIM uses for construction logistics, four were currently applied in practice – although seldom and not specifically for construction logistics optimization: 1) Data exchange with other project partners/ project disciplines; 2) Generating quantities from the 3D model; 3) Coupling of 3D model to a planning (4D modeling); and 4) Support of lean sessions with the model. The other BIM uses for construction logistics, which are not being applied yet in practice, were currently perceived to be too advanced to be applied in practice. Organizations that were interviewed and included in the study mainly applied BIM in a project for interface management (clash detection) and stakeholder management (using visualizations to communicate design intent). Moreover, there is still limited use of BIM uses for construction logistics by subcontractors and suppliers in practice, which impede the prime contractor from applying them in a project.

To support organizations in making the link between BIM and construction logistics, the PDEng trainee will create BIM scenarios for construction logistics. Each BIM scenario is composed of multiple BIM uses that describe a certain way of applying BIM to support construction logistics optimization. The BIM scenarios for construction logistics illustrate how BIM could be used to support construction logistics optimization within a specific collaboration setting, and their potential benefits for the participating organizations. The creation of the BIM scenarios will be discussed in the next chapter, Treatment design.

2.4.2. Product 2: Incentives for applying BIM uses for construction logistics

Incentives play an important role in the economic decision making of an organization. When positive incentives linked to BIM uses for construction logistics are available to an organization at the beginning of the project, then organizations are more willing to apply BIM uses for construction logistics. Based on the review of literature and professional publications, there are numerous possible incentives that can be used to motivate organizations to apply BIM uses for construction logistics. However, most of these incentives are rarely applied in practice. Moreover, as mentioned before, organizations currently do not often make the link between BIM and construction logistics. Incentives specifically for logistics optimization could motivate organizations to apply BIM uses for construction logistics. For these incentives to be effective, the awarding criteria should attach importance to demonstrating hard, concrete commitments that provide the contracting party (client or prime contractor) with certainty and that measures with corresponding effects are S.M.A.R.T.-ly defined.

For feasibility, the most important incentives among the 13 possible incentives will be chosen to be further developed in the next phase, treatment design (Chapter 3). For the 1st layer relationship, **risk sharing and sharing of savings were viewed as the most important incentives. In addition, MEAT criteria related to BIM and construction logistics were perceived as an effective and feasible incentive**. However, the design of risk sharing agreements involves complex preconditions and requires more extensive research, which fall outside the scope of this PDEng project. For the 2nd layer relationship, selecting organizations based on their BIM competence and readiness was seen as the most important incentive. However, this incentive motivates organizations to develop their BIM competence & readiness to increase chances of gaining future work, and is not directed towards the application of BIM uses for construction logistics in a specific project.

2.4.3. Product 3: Addendum to the BIM protocol

The BIM protocol contains agreements regarding BIM. It is added/attached to the contract that organizations enter into with each other. Agreements regarding definitions are common to all of the existing BIM protocols included in this review. These agreements include the definitions for Level-Of-Development (LOD) that are considered in the project, the standards that are applicable to the project, and the definitions of the BIM-related roles.

The most important part of a BIM protocol is the delivery scheme. The delivery scheme stipulates which information should be delivered to which organization, by which organization, in which Level-Of-Development (LOD), at which time, and in which format. However, most of the existing BIM protocols reviewed in this PDEng project did not contain a delivery scheme. A delivery scheme is important when applying BIM uses for construction logistics. When organizations fill-in a delivery scheme specifically for applying BIM uses for construction logistics, they become aware of both their own and of other organization’s logistics requirements. By agreeing upon a delivery scheme, organizations are held accountable for the correct and timely delivery of information throughout the construction process.

The BIM protocol can play an important role for keeping organizations to the terms of the incentives related to BIM. Currently, existing BIM protocols do not contain agreements specific to BIM uses for construction logistics or to incentives for applying BIM uses for construction logistics. Agreements regarding the delivery of information needed for the BIM uses for construction logistics and the incentives linked to the use of BIM should therefore be added to existing BIM protocols.

Chapter 3. Treatment design

In the problem investigation (Chapter 2), it was found that ① there is a need to make the benefits of BIM for construction logistics more explicit to clients, prime contractors, designers, subcontractors and suppliers in various collaboration settings. ② There is also a need for incentives that are specifically designed to motivate organizations to optimize construction logistics using BIM in a project, and ③ that these incentives should be anchored in the contracts between organizations, for example, in BIM protocols.

In this chapter, the design of three new products, which address the three needs described above, will be discussed. This chapter is structured into sections that correspond to the three design products. In the first section, the design of the BIM scenarios for construction logistics will be discussed (section 3.1), followed by the design of the incentives for applying BIM uses for construction logistics (section 3.2). The design of the addendum to the BIM protocol will be presented in section 3.3. The chapter ends with the conclusions on the treatment design in section 3.4.

"No matter which route home we take, Or what we forsake,
We're going to come up to the eyes of clarity."

-Joni Mitchell, Don Juan's Reckless Daughter

3.1 DESIGN OF THE BIM SCENARIOS FOR CONSTRUCTION LOGISTICS

In this section, the design of Product 1: BIM scenarios for construction logistics will be discussed. This section is structured into two subsections. First, the functional requirements that the BIM scenarios must fulfil will be given (subsection 3.1.1). Second, the design of the BIM scenarios for construction logistics will be discussed (subsection 3.1.2).

3.1.1. Functional requirements for the BIM scenarios

By itself, the benefits of BIM for construction logistics could motivate organizations to apply BIM in a project. When organizations perceive these benefits, it positively influences their intention to apply BIM uses for construction logistics in a project. Therefore, the main function of the BIM scenarios for construction logistics is to ***illustrate how BIM could be applied for construction logistics*** in various collaboration settings, so users of BIM scenarios would become aware of their potential benefits.

As determined from the problem investigation, defining (information) needs and bottlenecks related to construction logistics that a BIM scenario addresses is essential to identifying its potential benefits. Before perceiving the solution (BIM scenario for construction logistics), the future users of a BIM scenario for construction logistics should first recognize and acknowledge that there is a need related to construction logistics that must be addressed. For this, the trainee should ***specify the logistics requirements*** that the proposed solution could satisfy.

Once the logistics requirements are defined, possible solutions that address the logistics requirements can then be considered. Accordingly, the next step is to ***describe a possible solution*** using BIM uses for construction logistics for each of the logistics requirements. Using the resulting possible solutions, the PDEng trainee should then create and ***describe BIM scenarios for construction logistics***.

The BIM scenarios should ***specify the BIM requirements*** of organizations participating in the BIM scenario for construction logistics, and which BIM data each organization has to deliver to which requesting organization. Moreover, the BIM requirements should be specified for each organization in the various collaboration settings. The functional requirements for the BIM scenarios for construction logistics are illustrated in a FAST diagram (see Figure 7).

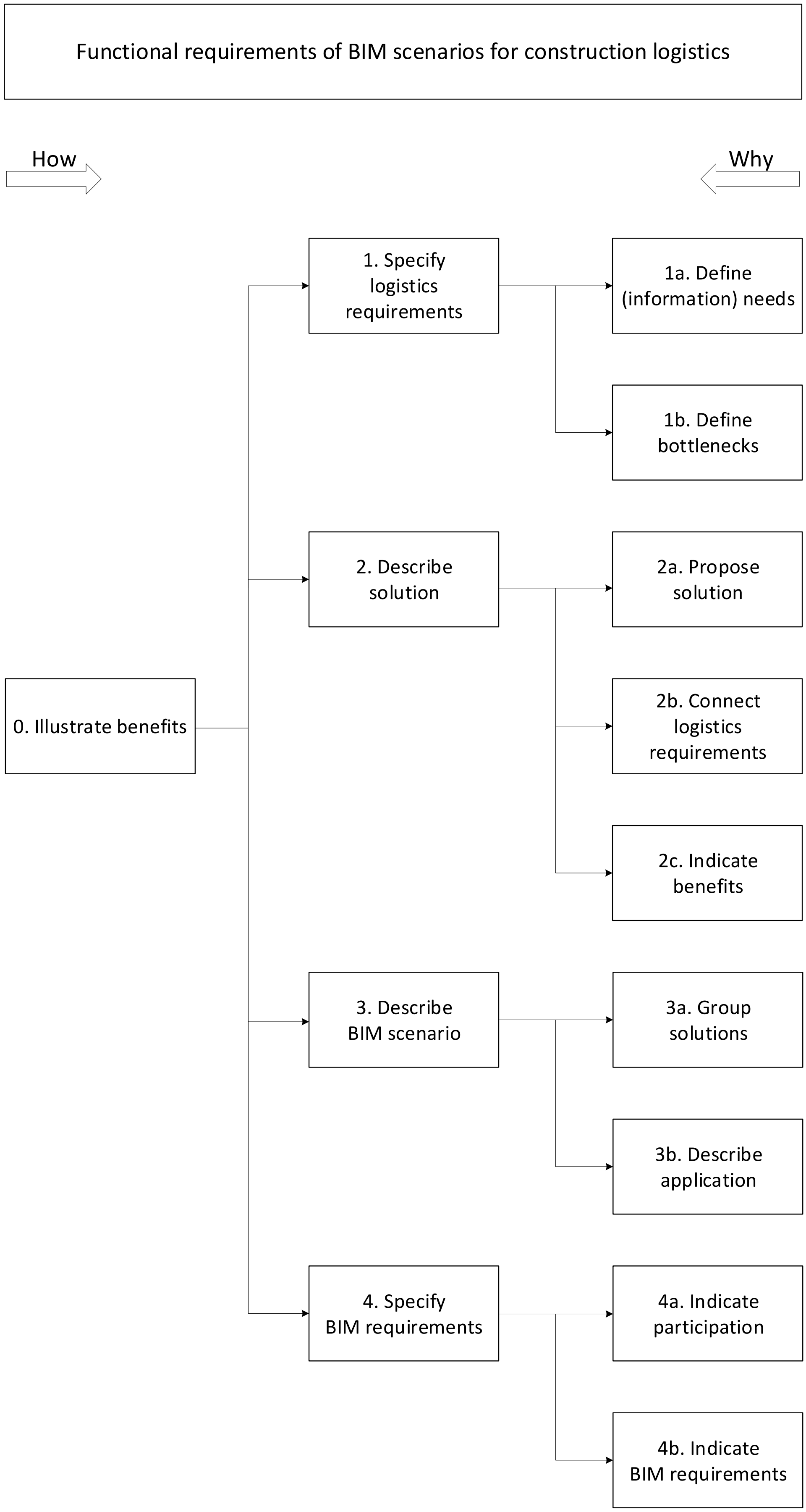


Figure 7. FAST diagram for Product 1: BIM scenarios for construction logistics.

3.1.2. Design of the BIM scenarios

To design the BIM scenarios, four steps, derived from the four functional requirements discussed above, were followed (illustrated by Figure **8**).

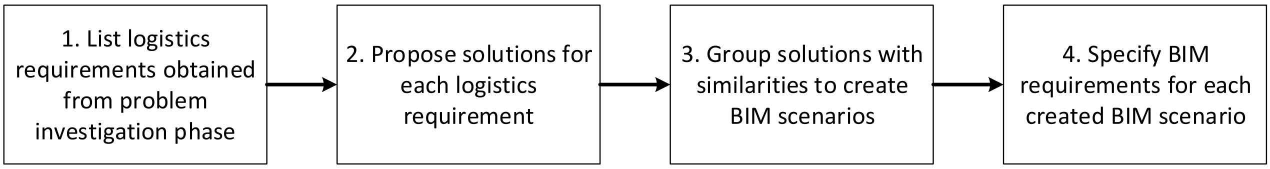
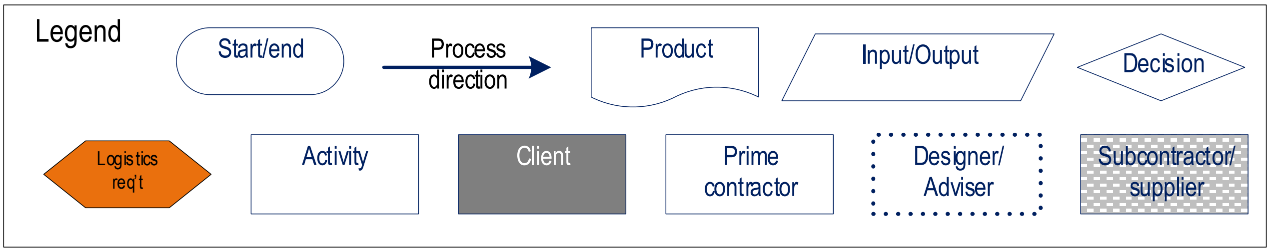


Figure 8. Steps followed in designing the BIM scenarios for construction logistics.

3.1.2.1. Logistics requirements

During the problem investigation phase, the PDEng trainee formulated logistics requirements. In subsection 2.1.1 (literature review on BIM uses for construction logistics), tasks of the client, prime contractor, designers, subcontractors and suppliers related to construction logistics were identified. From the results of the literature review, the PDEng trainee formulated logistics requirements for each organization and for each phase of the construction process. The formulated logistics requirements were then verified and appended during the case study (section 2.3). This resulted to a total of 14 logistics requirements.

To show where the logistics requirements can be found in the logistics process, the PDEng trainee created a process scheme (shown in Figure **9**). Figure **9** is a visual representation of the logistics tasks of organizations, which were obtained from literature review (subsection 2.1.1) and then validated through the case study (section 2.3). In Figure **9**, the logistics requirements are symbolized as a hexagon and numbered as L1 to L14. The logistics requirements L1 to L14 are then explained in Table **22** with some examples.



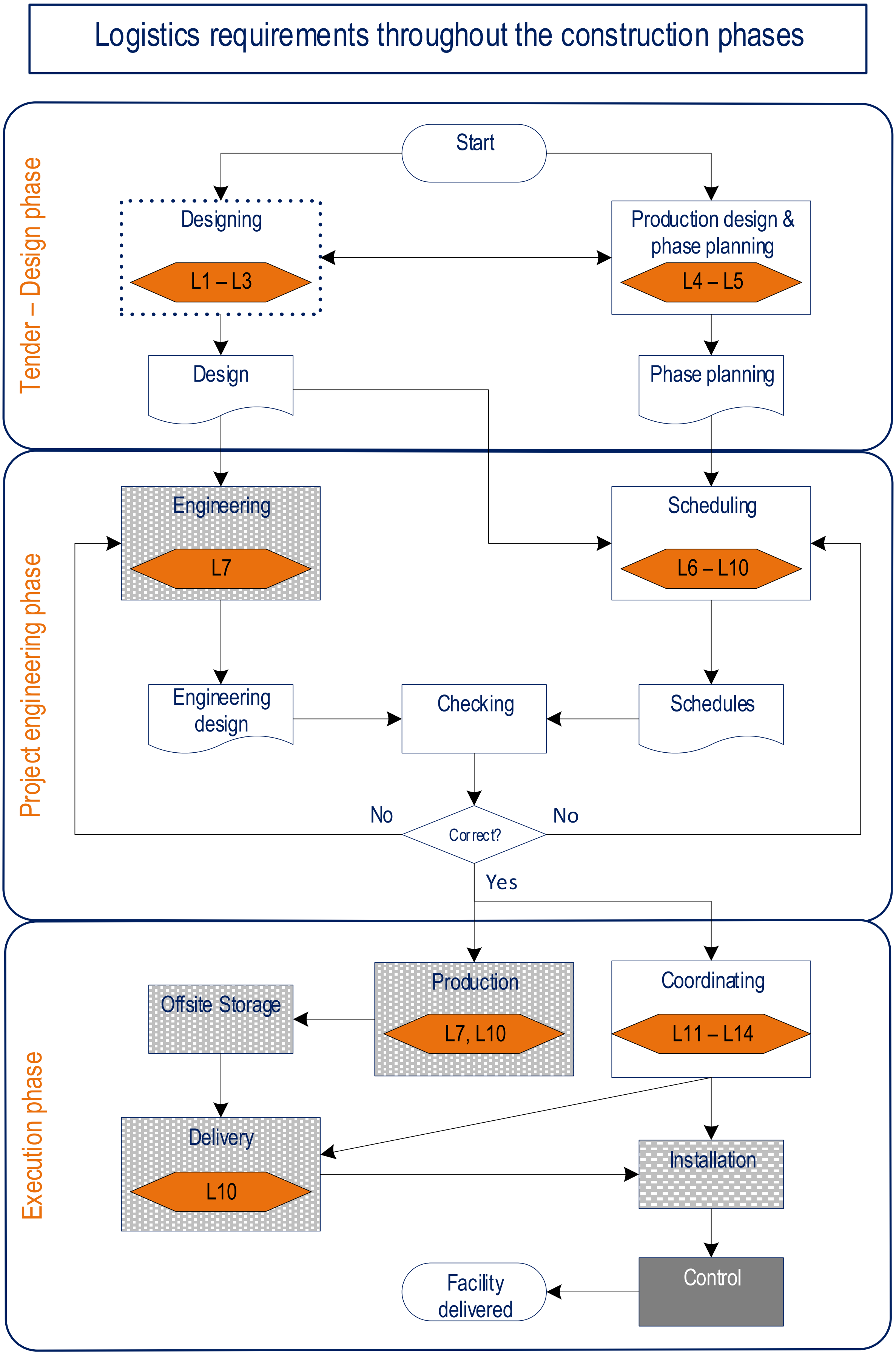


Figure 9. Logistics map without the use of BIM, with logistics requirements

Table 22. Logistics requirements with examples.

Phase	#	Organization	Logistics requirements	Examples
(FOR INTEGRATED CONTRACTS) Tender - Design phase	L1	Designer	Align designs from various disciplines, which results to less design errors and consequently, less disruptions to the execution and logistics process.	Combine architectural, structural and MEP designs and check these designs for interface clashes.
	L2	Designer	Consistently process design changes in all drawings, which results to less errors in drawings and consequently, less disruptions to the execution and logistics process.	
	L3	Designer	Align the design with the circumstances on site.	Align the daily concrete supply need with the supply possibilities on site, or test the available space on site for temporary facilities and cranes.
	L4	Client, Prime contractor	Efficiently analyze and compare effects of alternative construction phase planning and risk mitigation strategies on traffic flows and the availability of public and temporary roads.	
	L5	Prime contractor	Optimize construction method and construction sequence, and eventually optimize design	Align the use and installation of rebar meshes with the design. Support the choice for prefab or cast-in-situ concrete.
Project engineering phase	L6	Prime contractor	Clearly visualize and communicate the location, context and quantity of specific elements with certain specifications (what, where and how much).	Select and visualize all prefab floor panels in one model, so that their location and context are clear.
	L7	Prime contractor, Subcontractors/ suppliers	Independently generate and use information out of the design.	Generate site/floor plans, cross-sections and 2D drawings. Use the 3D model as basis for engineering and production of steel constructions.
	L8	Prime contractor	Align production models from various disciplines with each other, which results to less design errors and consequently, less disruptions to the construction and logistics process.	Combine production models from steel suppliers and prefab concrete suppliers, and check these designs for interface clashes.
	L9	Prime contractor	Independently navigate through the design from each possible perspective and at various moments during the construction process to gain insight into the conditions for execution.	Check if there is enough room for specific operations or storage.
	L10	Prime contractor, Subcontractors/ suppliers	Determine what, when and how much should be delivered, and eventually optimize delivery options	View what and how much should be delivered in a day, and optimize bundling of packages to maximize truck load and minimize traffic movements.

Continuation of Table 22. Logistics requirements with examples.

Execution phase	L10	Subcontractors/ suppliers	Determine what, when and how much should be delivered, and eventually optimize delivery options	View what and how much should be delivered in a day, and optimize bundling of packages to maximize truck load and minimize traffic movements.
	L11	Prime contractor	Monitor if orders will be delivered on time, and view the consequences of delivery time on construction activities.	View if a 3D object has been purchased or delivered. Receive a notification when a delivery will be delayed and view its consequences for the critical path.
	L12	Prime contractor	Manage the stock on site.	View by a storage location which and how much materials are stored there.
	L13	Prime contractor	Align on a detailed level which party is working where and when.	Visualize which working teams are working in which areas and where detailed coordination is needed.
	L14	Prime contractor	Optimize use of space on site.	

3.1.2.2. Solutions

Solutions using BIM uses for construction logistics are proposed for each logistics requirement, resulting to 11 solutions in total. These 11 solutions are presented in the boxes (Box **1** to Box **11**).

Box 1. Solution #1.

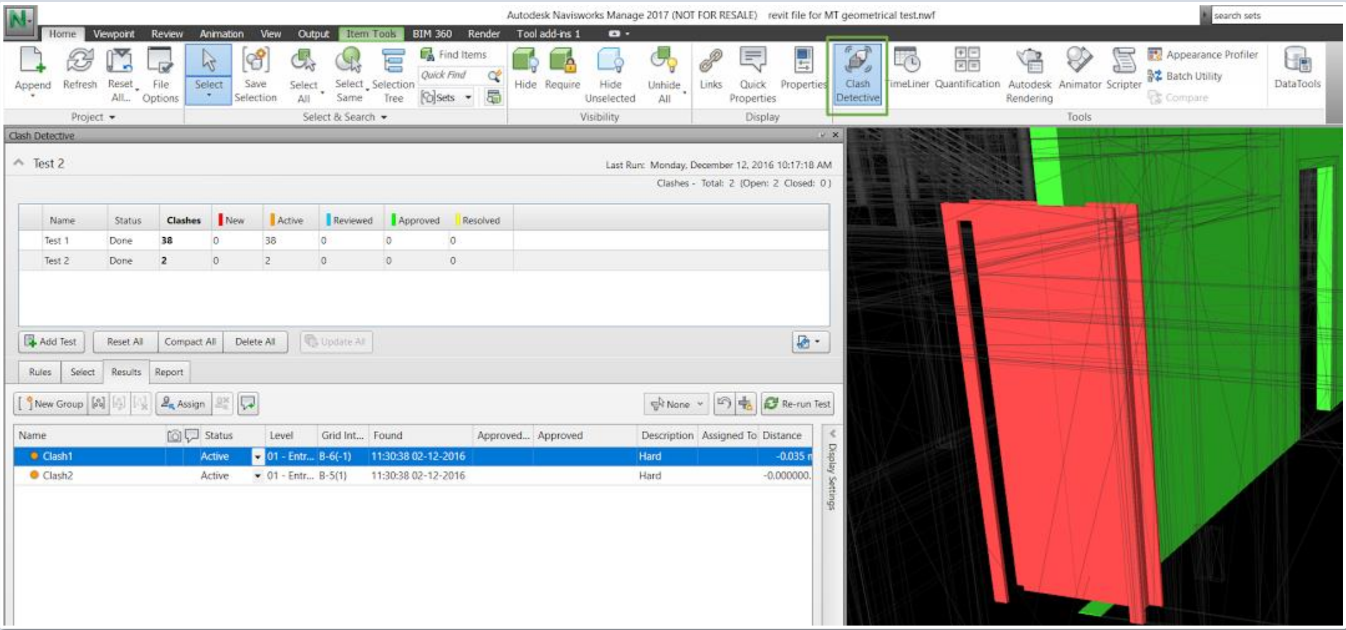
Logistics requirement #1

- Align designs from various disciplines, which results to less design errors and consequently, less disruptions to the execution and logistics process.

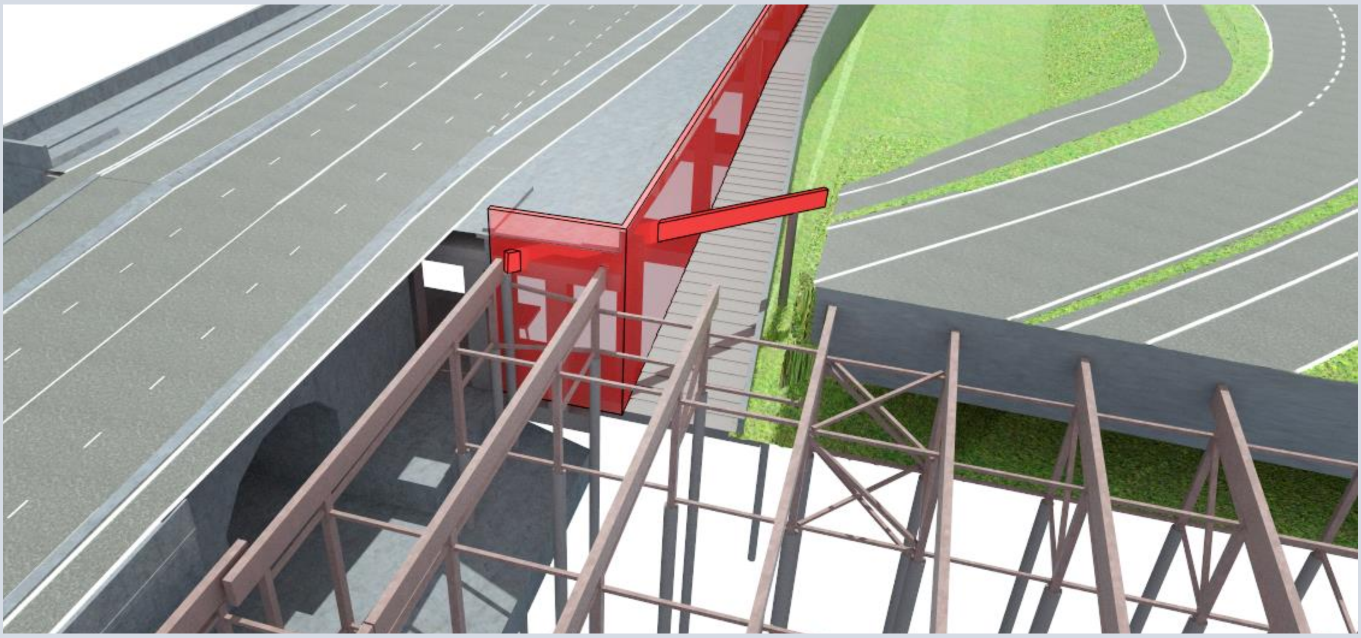
Solution #1:

- Make a 3D model for each design discipline
- Integrate 3D models from design disciplines
- Check the 3D models for interface clashes or other errors

Examples:



Clash control (*image from New Lock Terneuzen project*)



Interface management between definite and temporary facilities (*image from New Lock Terneuzen project*)

Box 2. Solution #2.

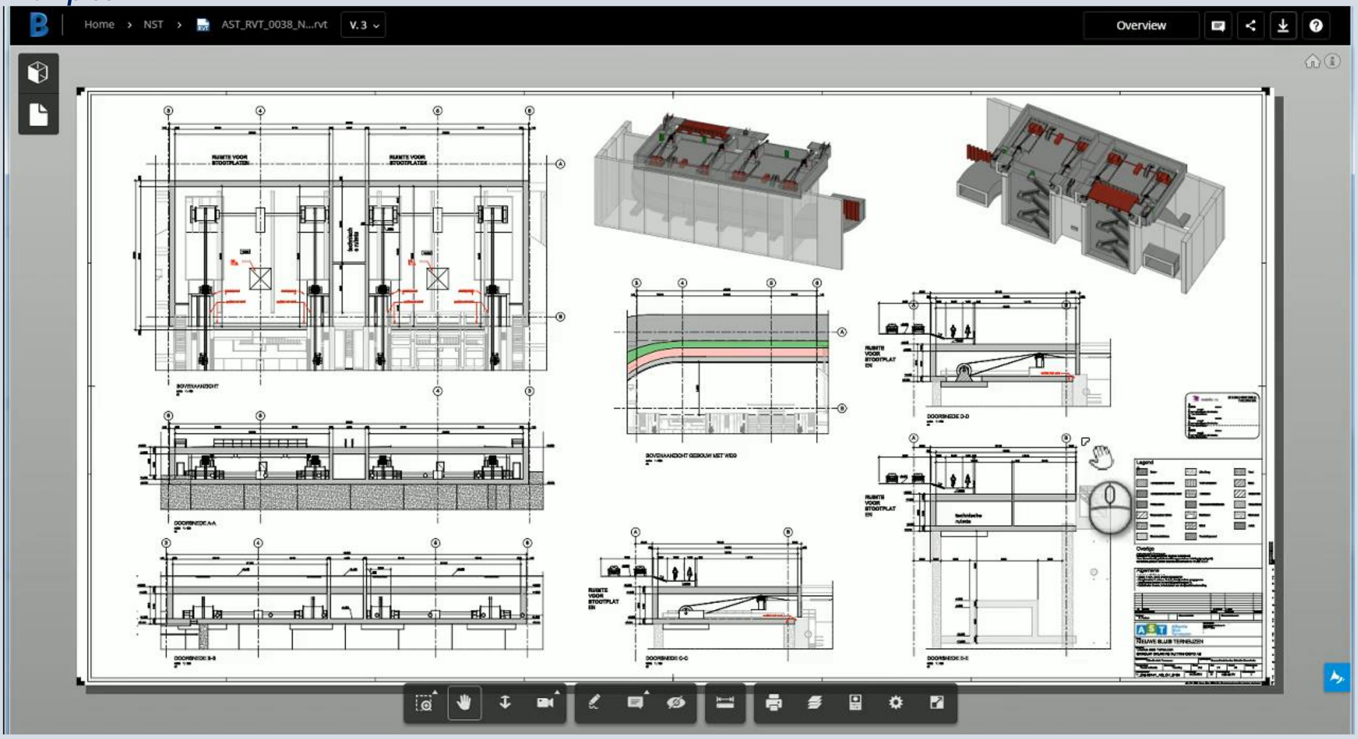
Logistics requirements #2 and #7

- Consistently process design changes in all drawings, which results to less errors in drawings and consequently, less disruptions to the execution and logistics process.
- Independently generate and use information out of the design.

Solution #2:

- 3D modeling/designing
- Information is entered once, is consistent (uniform) and non-redundant
- Generate 2D drawings from the 3D model
- Use 3D model as basis for 3D production model

Examples:



Generating 2D drawings from the 3D model (*image from New Lock Terneuzen project*)

Box 3. Solution #3.

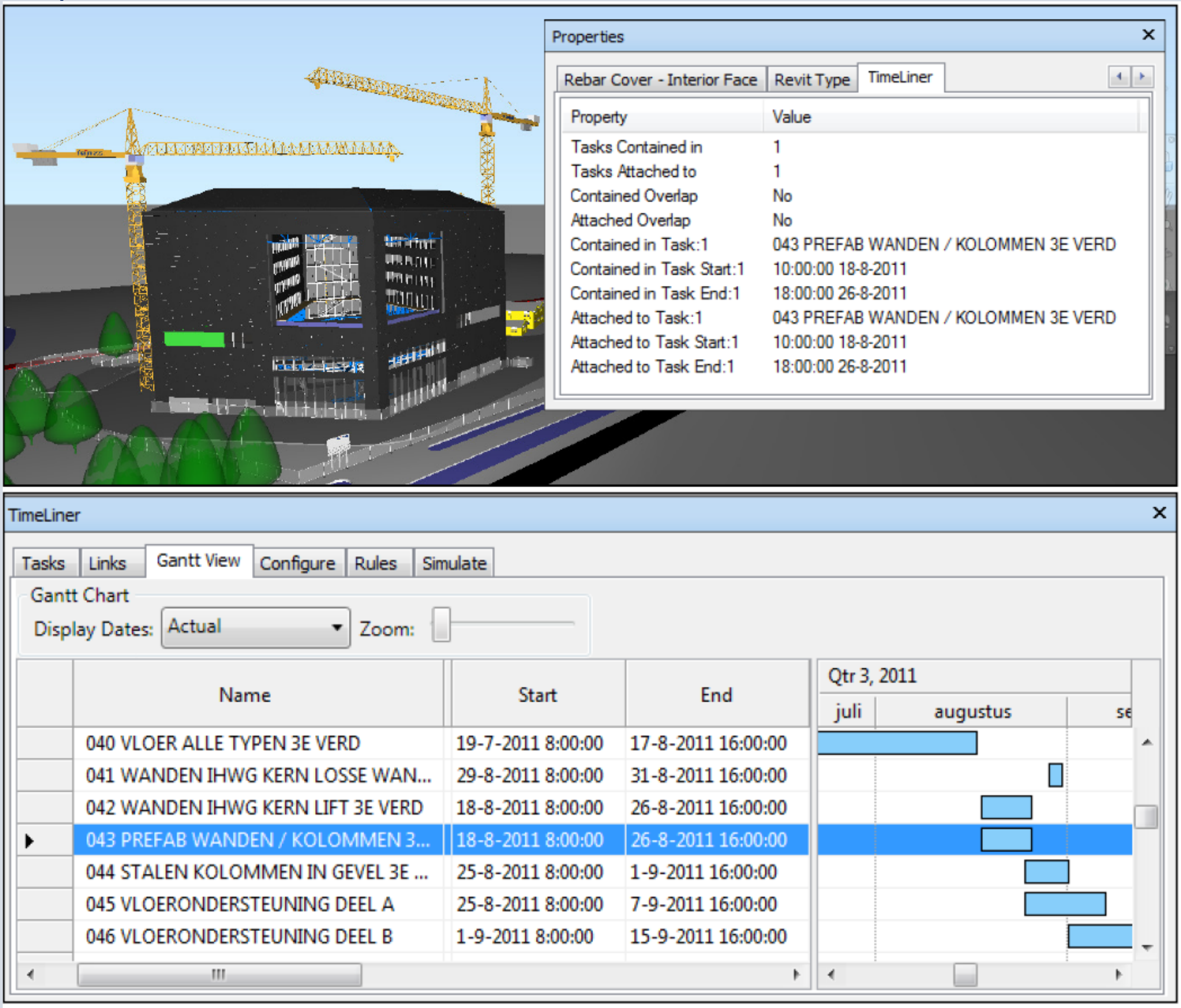
Logistics requirement #3

- Align the design with the circumstances on site.

Solution #3:

- Make a 3D model for each design discipline
- Make a 3D model of temporary facilities and cranes
- Integrate the 3D models and link with execution schedules
- Generate quantities of materials required to be supplied for each time unit (day, week, etc.)
- Visualize construction site design for each time unit, and eventually optimize design

Examples:



Linking of objects to activities (*image from Zuiker (2012, p. 88)*)

Box 4. Solution #4.

Logistics requirement #4

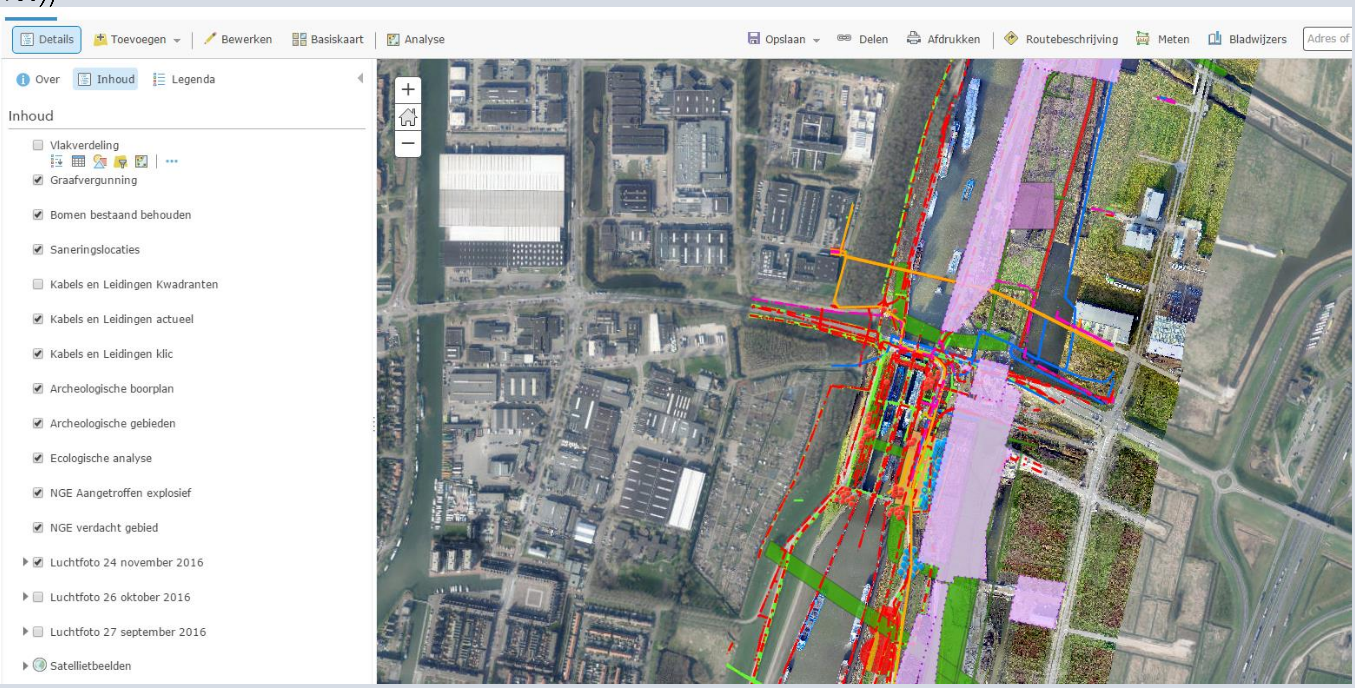
- Efficiently analyze and compare effects of alternative construction phase planning and risk mitigation strategies on traffic flows and the availability of public and temporary roads.

Solution #4:

- Make a 3D model for each design discipline
- Make a 3D model of temporary facilities and cranes
- Integrate these 3D models and link with execution schedules
- Use 4D model to show where and when nuisance to public and temporary roads will take place
- Link 3D/4D model with traffic simulation models
- Link 3D/4D model with GIS

Examples:

Highlighting parts of an affected traffic network (*image from Zanen, Hartmann, Al-Jibouri, and Heijmans (2013, p. 139)*)



Link 3D model with GIS (*image from New Lock Terneuzen project*)

Box 5. Solution #5.

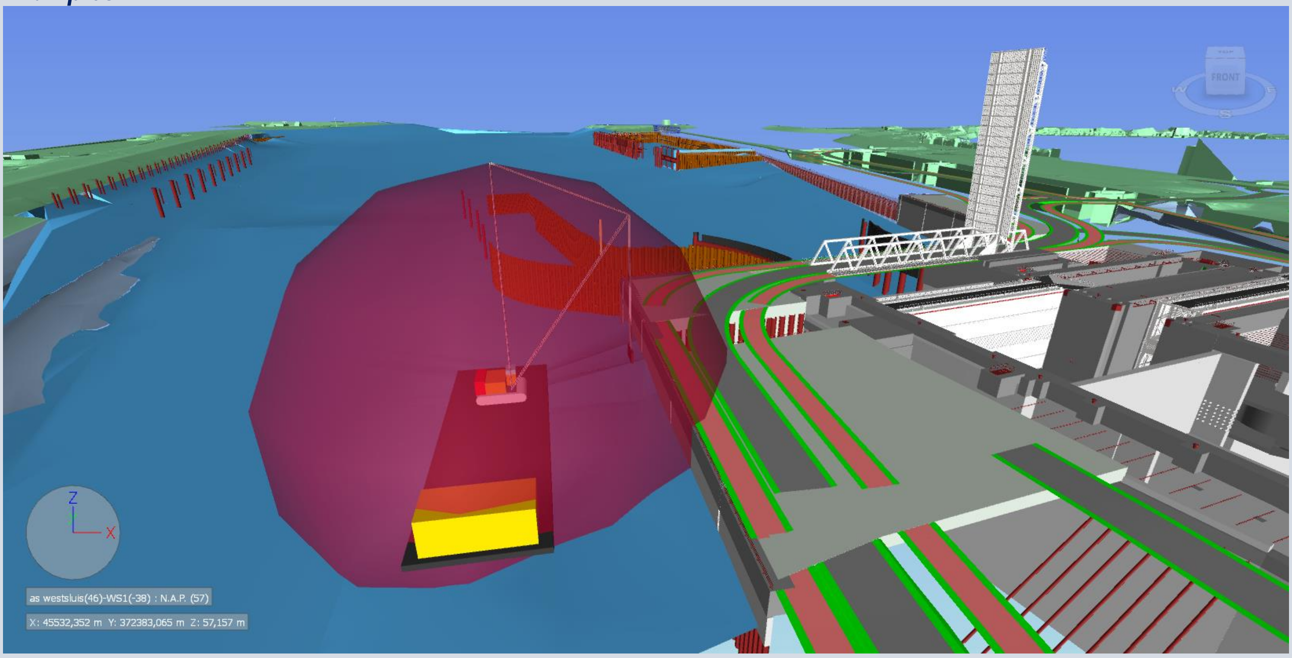
Logistics requirement #5

- Optimize construction method and construction sequence, and eventually optimize design.

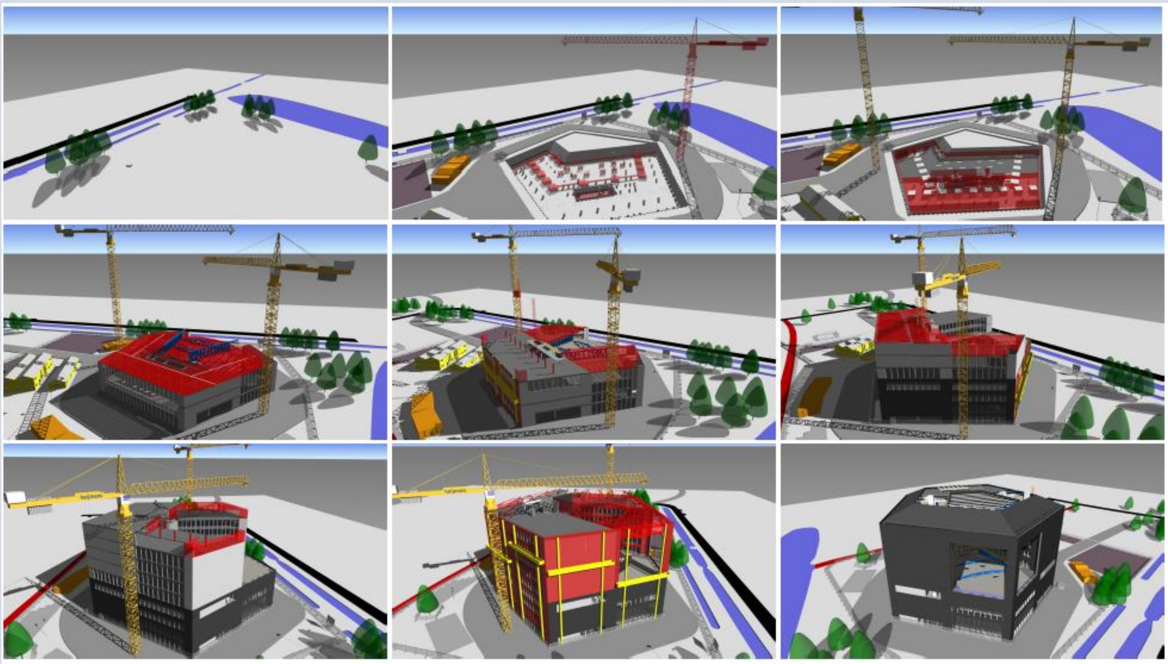
Solution #5:

- Make a 3D model for each design discipline
- Make a 3D model of temporary facilities and cranes
- Integrate these 3D models
- Link with execution schedules
- Visualize and optimize construction activities that largely determine and/or significantly affect the project duration (critical path)

Examples:



Visualizing work areas of temporary equipment (*image from New Lock Terneuzen project*)



Visualize construction sequence (*image from Zuiker (2012, p. 93)*)

Box 6. Solution #6.

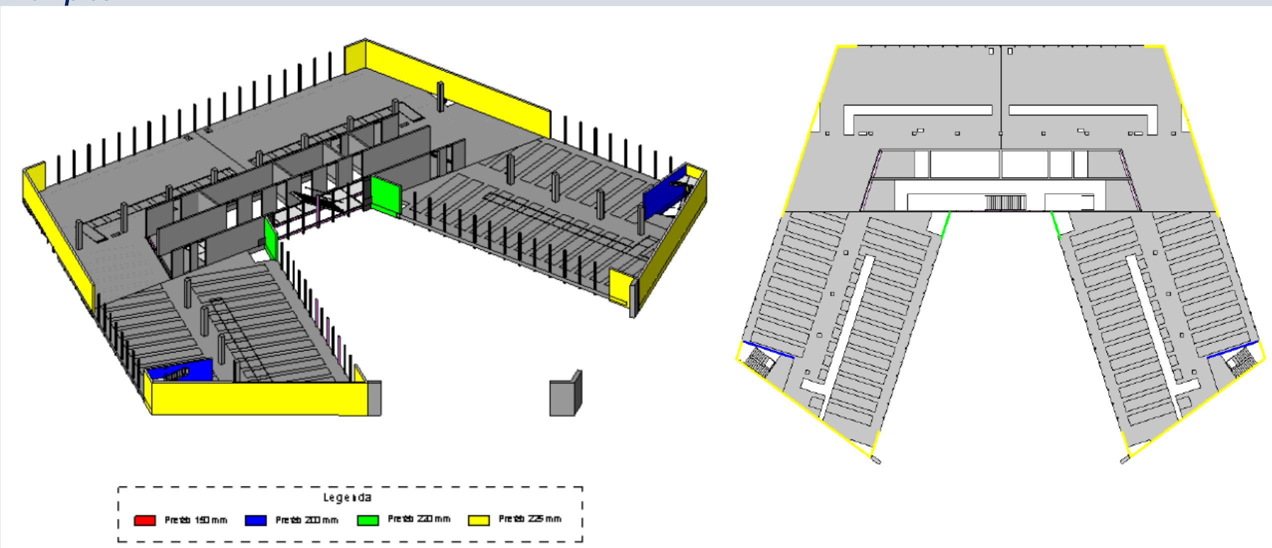
Logistics requirements #6 and #7

- Clearly visualize and communicate the location, context and quantity of specific elements with certain specifications (what, where and how much).
- Independently generate and use information out of the design.

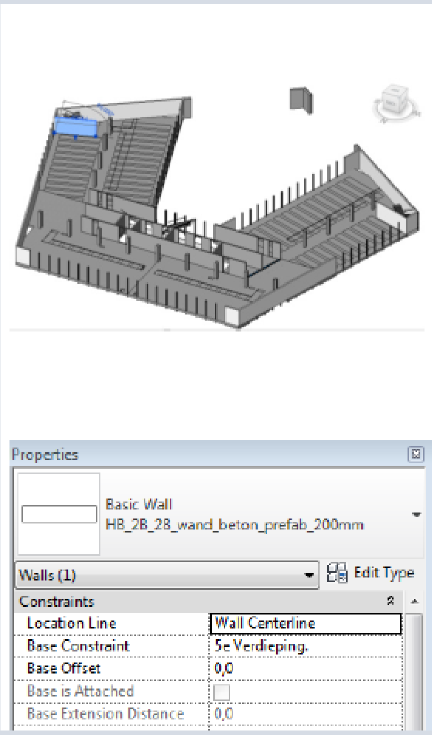
Solution #6:

- Receive integrated 3D design model
- Generate 2D drawings from the 3D model
- Use of filters and query on element type and parameter
- Make a 3D production model

Examples:



Use of filters on element type (prefab walls) (*image from Zuiker (2012, p. 90)*)



TYPE PROPERTIES

Family	**Basic Wall**
Type	**HB_2B_28_wand_beton_prefab_200mm**
Description	prefab beton
Type Comments	Dragend binnenwand element
HB-00_bestekscode	23.50.31-b
HB_00_URL_bestekalgemeen	//bestek/H23.pdf
HB_00_bevestiging_verankering	conform specificaties fabrikant. Bevestiging volgens ontwerpgegevens.
HB_00_bindmiddel	Cement, conform specificaties fabrikant.
HB_00_brandveiligheid(min)	60
HB_00_kantuitvoering	
HB_00_milieuklasse_beton	XC1
HB_00_oplegging	Ondersabeling met krimparme mortel conform besteksspost 23.82.10-a.01. Oplegvoorziening conform specificaties fabrikant.
HB_00_oppervlak_ontkiste_zijde	Klasse B vlak en glad en kleur conform referentievlak
HB_00_oppervlak_stortzijde	Klasse C, vlak onder de rij en gerold (niet in het zicht)
HB_00_staalkwaliteit wapening	Netten tot Ø 12 mm FeB 500 HKN toegestaan, netten boven Ø12 mm en alle wapening in staven FeB 500 HWL, voorspanwapening: FeB 1670 / 1770, volgens tekening en berekening leverancier, minimaal 85 kg/m3
HB_00_sterkteklasse_beton	Conform specificaties fabrikant, minimaal

View geometric and non-geometric properties of elements (*image from (Zuiker, 2012, p. 88)*)

Box 7. Solution #7.

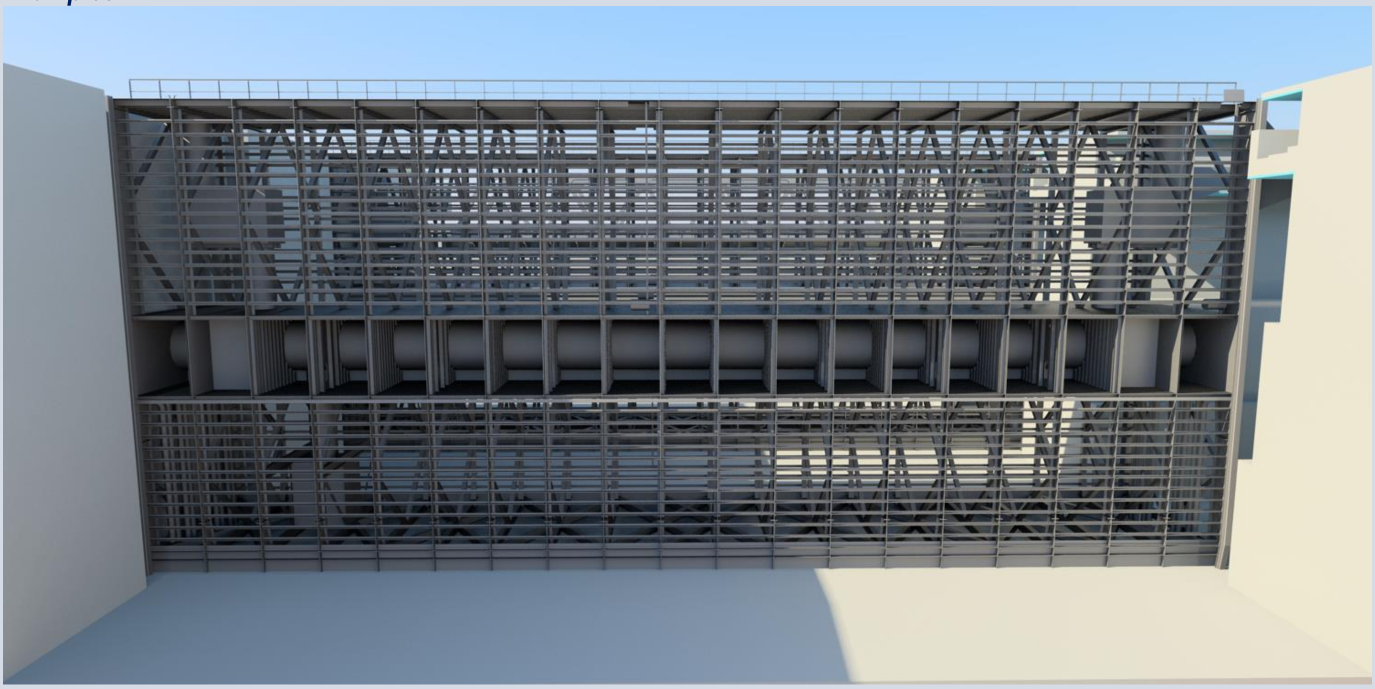
Logistics requirement #8

- Align production models from various disciplines with each other, which results to less design errors and consequently, less disruptions to the construction and logistics process.

Solution #7:

- Make a 3D production model for each supplier
- Integrate 3D design model and 3D production models
- Check the 3D models for interface clashes or other errors

Examples:



Integrate 3D production model of lock gate with 3D design model (*image from New Lock Terneuzen project*)

Box 8. Solution #8.

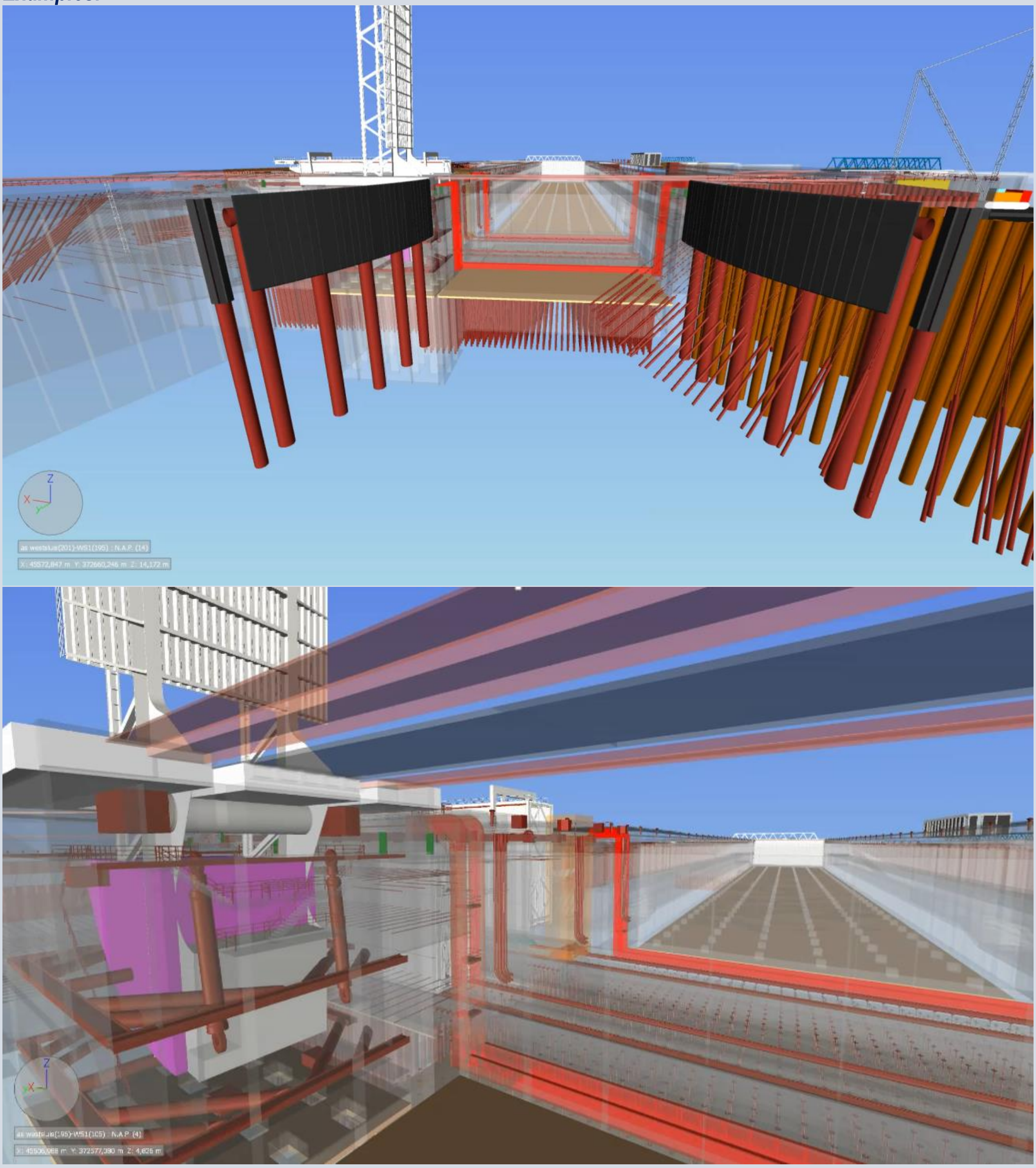
Logistics requirement #9

- Independently navigate through the design from each possible perspective and at various moments during the construction process to gain insight into the conditions for execution.

Solution #8:

- Navigate in 4D model
- Use of viewpoints and tags

Examples:



Navigate from each possible perspective in 4D model

Box 9. Solution #9.

Logistics requirement #10

- Determine what, when and how much should be delivered, and eventually optimize delivery options.

Solution #9:

- Receive integrated 3D design model
- Link with a schedule (production schedule, delivery schedule or execution schedule)
- Use 4D model to determine moment of preparation, production, delivery and execution of an object
- Generate quantity of materials to be delivered for a specific day
- View geometric properties and packaging properties of objects to be delivered for a specific day and optimize bundling of objects, to maximize truck load and minimize traffic movements

Examples:

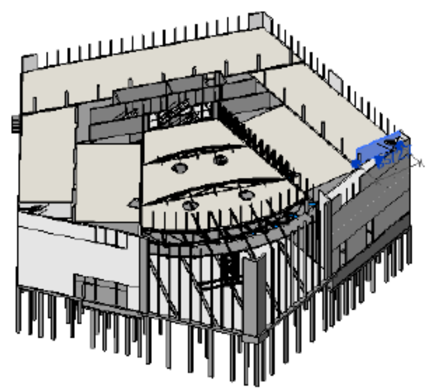
Schedule: A- Prefab Wanden - Orion WUR_constructie_Anke.rvt

Type	Count	Type Comments	HB-00_bestekscode	HB_00_oppervlak_stortzijde	HB_00
HB_2B_28_wand_beton_prefab_150mm	2	Dragend binnenwand element	23.50.31-b	Klasse C, vlak onder de rij	XC2
HB_2B_28_wand_beton_prefab_200mm	12	Dragend binnenwand element	23.50.31-b	Klasse C, vlak onder de rij	XC1
HB_2B_28_wand_beton_prefab_220mm	14	Dragend binnenwand element	23.50.31-b	Klasse C, vlak onder de rij	XC1
HB_2B_28_wand_beton_prefab_225mm	102	Dragend binnenspouwblad element	23.50.21-b	Klasse C, vlak onder de rij	XC2

Schedule: A- Prefab Wanden per stuk - Orion WUR_constr...

A- Prefab Wanden per stuk

Type	Length	Width	Volume	Area
HB_2B_28_wand_beton_prefab_150mm	4000	150	1,82 m³	12,13 m²
HB_2B_28_wand_beton_prefab_150mm	1462	150	0,62 m³	4,13 m²
HB_2B_28_wand_beton_prefab_200mm	8573	200	5,84 m³	29,19 m²
HB_2B_28_wand_beton_prefab_200mm	8578	200	5,84 m³	29,21 m²
HB_2B_28_wand_beton_prefab_200mm	6825	200	5,17 m³	25,84 m²
HB_2B_28_wand_beton_prefab_200mm	6840	200	5,18 m³	25,90 m²
HB_2B_28_wand_beton_prefab_200mm	6825	200	5,17 m³	25,84 m²
HB_2B_28_wand_beton_prefab_200mm	6840	200	5,18 m³	25,90 m²
HB_2B_28_wand_beton_prefab_200mm	6825	200	5,17 m³	25,84 m²
HB_2B_28_wand_beton_prefab_200mm	6840	200	5,18 m³	25,90 m²



Link between element and quantity (*image from Zuiker (2012, p. 99)*)

Box 10. Solution #10.

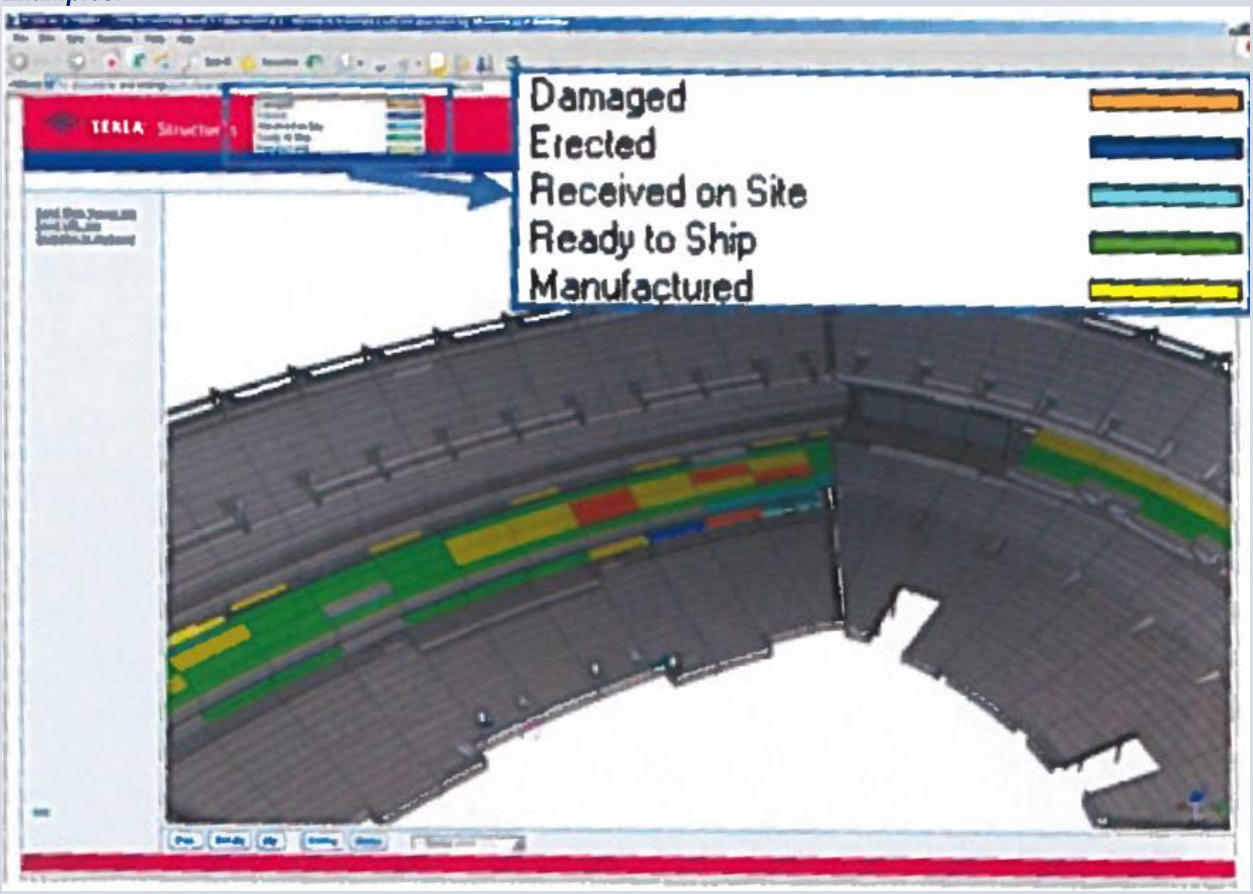
Logistics requirements #11 and #12

- Monitor if orders will be delivered on time, and view the consequences of delivery time on construction activities.
- Manage the stock on site.

Solution #10:

- Receive integrated 3D design model and link with a schedule
- Use 4D model to monitor the status and moment of preparation, production, delivery and execution of an object
- Link with wireless technology such as RFID-tags and barcodes
- Use of equipment to scan RFID-tags and barcodes, so that location of objects can be viewed in the model
- Use 3D/4D model to view the status of objects, such as 'in production' or 'in storage'

Examples:



Visualize status of elements using color schemes (*image from Eastman et al. (2011, p. 332)*)

Box 11. Solution #11.

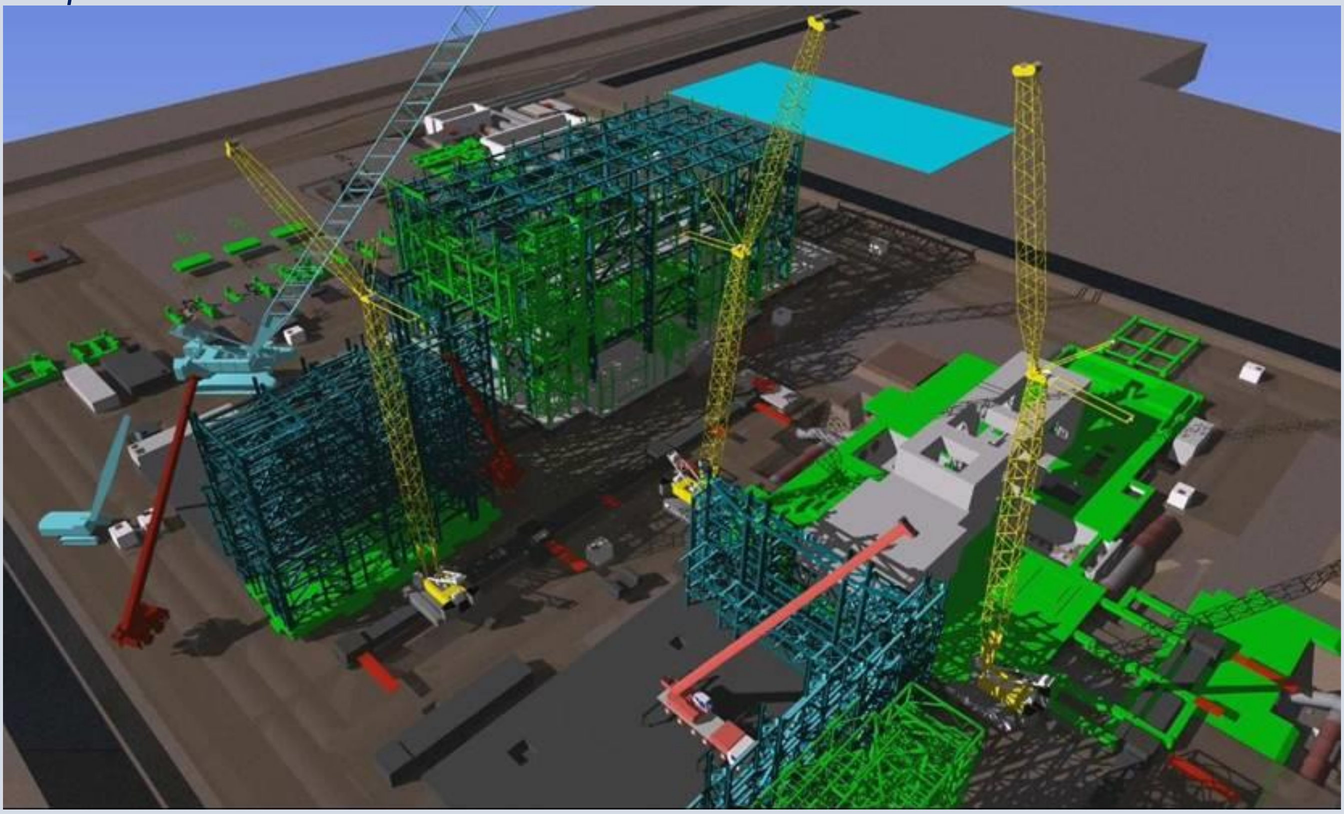
Logistics requirements #13 and #14

- Align on a detailed level which party is working where and when.
- Optimize use of space on site.

Solution #11:

- Use 4D model to visualize permanent and temporary facilities on site, including a schedule of activities
- Manage storage locations, access routes to the site, setup of temporary facilities and cranes

Examples:



Visualize permanent facilities and cranes on site

3.1.2.3. *Grouping of the solutions to create BIM scenarios for construction logistics*

The 11 proposed solutions were then grouped to create BIM scenarios for construction logistics. Solutions with similar steps were grouped together. Table **23** lists the resulting groups of solutions.

Table 23. Groups of solutions using BIM uses for construction logistics.

Group 1	Group 2	
Solution #1 Solution #2 Solution #6 Solution #7	Solution #3 Solution #4 Solution #5 Solution #8	Solution #9 Solution #10 Solution #11

Each resulting group will make up a BIM scenario for construction logistics:

- Group 1 – BIM scenario 1: Data exchange using BIM
- Group 2 – BIM scenario 2: Coupling of 3D model to a planning (4D modeling)

The two BIM scenarios will be discussed next.

BIM scenario 1: Data exchange using BIM
Data exchange using BIM is a process in which the model is used for storing and exchanging data. The model serves as a repository of data that can be retrieved by multiple applications used by project partners/ project disciplines working in the same project (Eastman et al., 2011). Information is entered once, is consistent (uniform) and non-redundant.

The following steps and possible uses, which were obtained from the proposed solutions, make up BIM scenario 1: Data exchange using BIM. Figure 10 and Figure 11 illustrate the application of this BIM scenario in a Design-Bid-Build and Design-Build setting, respectively.

1) Make a 3D model for each design discipline
2) Integrate 3D models from design disciplines
3) Check the 3D models for interface clashes or other errors
4) Apply filters on element type and parameter for purchasing demarcation
5) Use integrated 3D model as basis for 3D production model
6) Make a 3D production model for each supplier
7) Integrate 3D design model and 3D production models
8) Check the 3D models for interface clashes or other errors
9) Generate 2D drawings from the 3D model
10) Generate documents from the 3D model
11) Generate quantities from the 3D model

Table 25 lists which information related to construction logistics should be delivered by which organization, in which phase of the construction process, and to which organization.

BIM scenario 2: Coupling of 3D model to a planning (4D modeling)
4D modeling is a process in which the 3D geometries and location of objects in the model are linked to temporal information, such as the timings of their production, delivery or construction. An advantage of model-based scheduling is that it captures the spatial components related to activities, and directly links activities with the design (Computer Integrated Construction Research Program, 2010). Through this link, the schedule can remain in sync with the design, and stakeholders are able to easily understand the schedule, evaluate its feasibility and its impact on logistics.

The following steps and possible uses, which were obtained from the proposed solutions, make up BIM scenario 2: Coupling of 3D model to a planning. Figure 12 and Figure 13 illustrate the application of this BIM scenario in a Design-Bid-Build and Design-Build setting, respectively.

1) Make a 3D model for each design discipline
2) Make a 3D model of temporary facilities and cranes
3) Integrate 3D models and check for clashes and other errors
4) Link 3D model with (production, delivery, or execution) schedule
5) Use 4D model to show where and when nuisance to public and temporary roads will take place
6) Use viewpoints and tags
7) Link 3D/4D model with traffic simulation models
8) Link 3D/4D model with GIS
9) Link with wireless technology such as RFID-tags and barcodes
10) Use of equipment to scan RFID-tags and barcodes, so that location of objects can be viewed in the model
11) Use 3D/4D model to view the status of objects, such as ‘in production’ or ‘in storage’
12) Manage storage locations, access routes to the site, setup of temporary facilities and cranes

The resulting 4D model can be used for multiple purposes:

- visualize construction site design for each time unit, and eventually optimize design
- visualize and optimize construction activities that largely determine and/or significantly affect the project duration (critical path)
- determine moment of preparation, production, delivery and execution of an object
- generate quantity of materials to be delivered for a specific day
- view geometric properties and packaging properties of objects to be delivered for a specific day and optimize bundling of objects, to maximize truck load and minimize traffic movements

When the two BIM scenarios for construction logistics are applied in a project, organizations will have BIM data requirements from each other. The BIM data requirements of organizations during each phase of the construction process will be discussed next.

3.1.2.4. BIM requirements

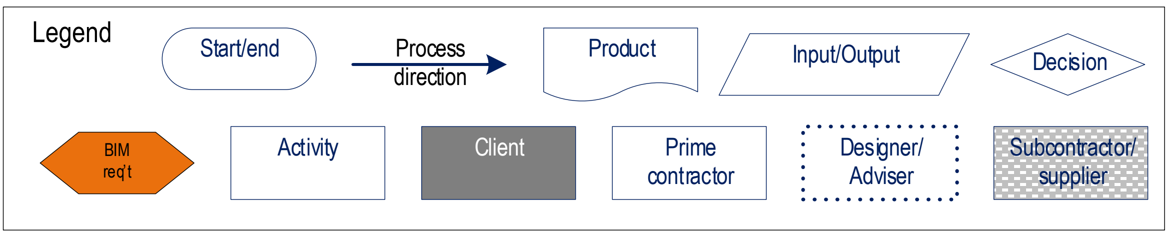
The solutions using BIM scenarios for construction logistics can be applied to fulfil the logistics requirements of organizations. Consequently, the application of these solutions in a project correspond to BIM requirements. Organizations have to agree on which BIM data should be delivered, and when and how they should be delivered to apply these solutions in a project.

As discussed in sections 2.1.1, 2.2.1 and 2.3.1, the BIM requirements of organizations vary depending on the collaboration setting in a project. Similar to logistics requirements, organizations have additional BIM requirements in integrated contracts (Design-Build) above the BIM requirements in traditional/ low integration collaboration settings. The additional BIM requirements, which are found during the tender to design phase, are required to ensure the (re)use of BIM data for construction logistics during the project engineering and execution phases. When organizations strategically collaborate together on multiple projects and make use of advanced compensation schemes (integrated supply chain), then organizations can spread the costs of investments needed for the additional BIM requirements across multiple projects. Furthermore, since organizations will become familiar with each other's BIM requirements in future projects, then organizations can save the time spent on aligning BIM-related products and practices in future projects.

There are two variations for each of the two BIM scenarios for construction logistics: one with Design-Bid-Build, and another with Design-Build. The BIM requirements in these four scenarios are illustrated in the next four figures. Table **24** gives an overview of the four figures.

Table 24.

Figure #	Shows the position of BIM requirements for:
Figure **10**	**BIM scenario 1**: Data exchange using BIM with a traditional contract (**Design-Bid-Build**)
Figure **11**	**BIM scenario 1**: Data exchange using BIM with an integrated contract (**Design-Build**)
Figure **12**	**BIM scenario 2**: 4D modeling with a traditional contract (**Design-Bid-Build**)
Figure **13**	**BIM scenario 2**: 4D modeling with an integrated contract (**Design-Build**)



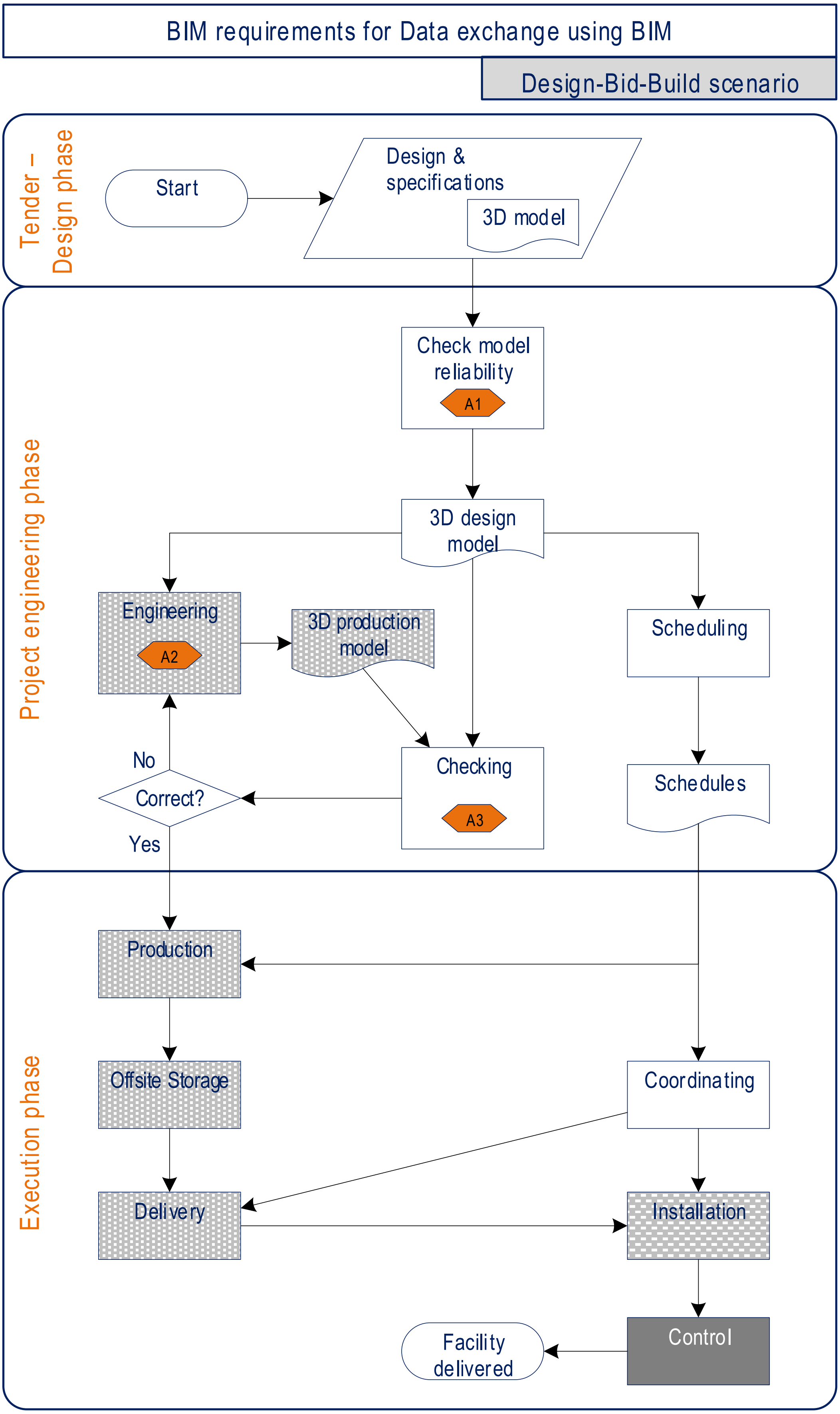


Figure 10. BIM requirements for BIM scenario 1 – Design-Bid-Build.

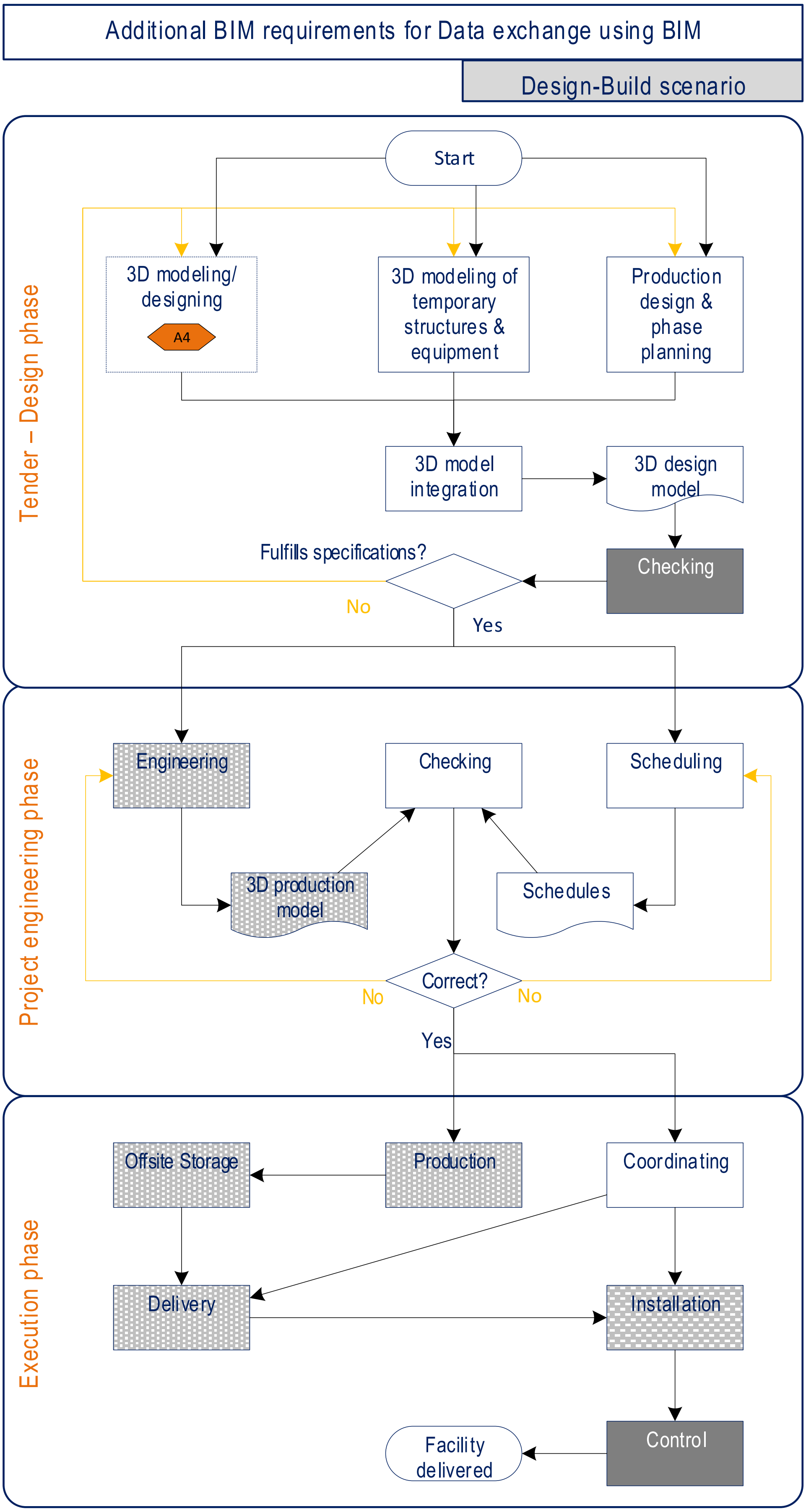


Figure 11. BIM requirements for BIM scenario 1 – Design-Build.

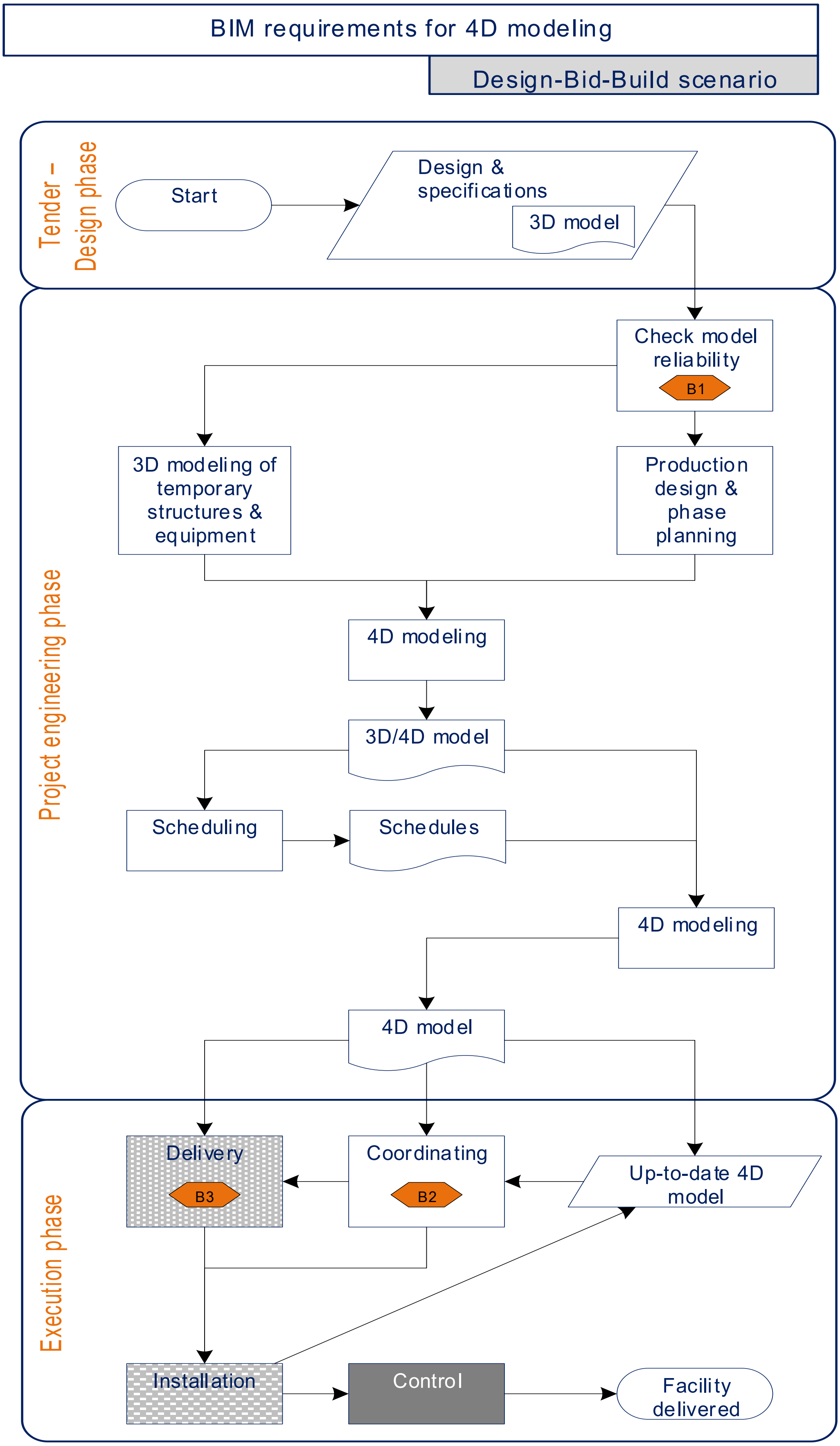


Figure 12. BIM requirements for BIM scenario 2 – Design-Bid-Build.

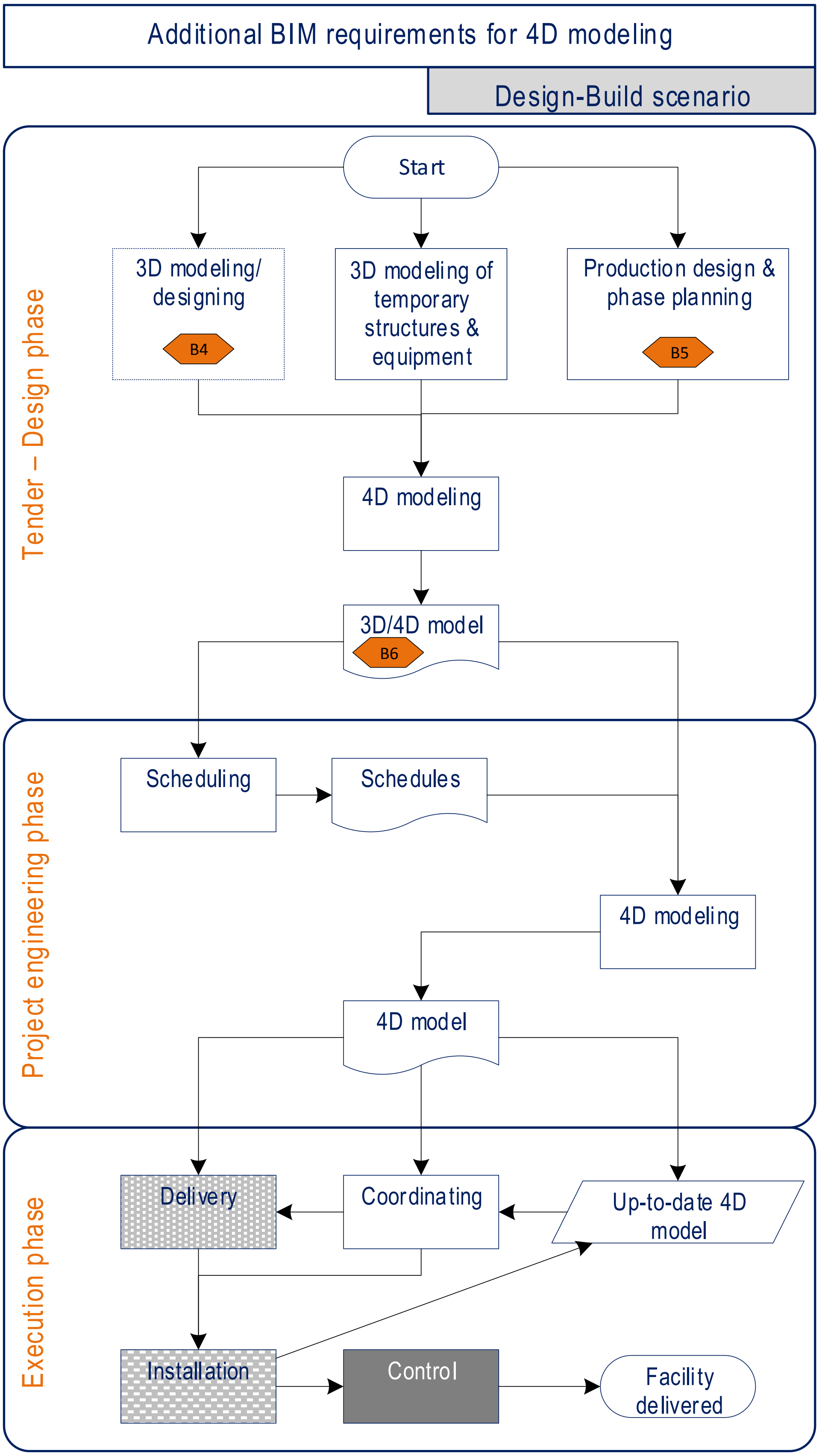


Figure 13. BIM requirements for BIM scenario 2 – Design-Build.

The BIM requirements in the figures above are explained in Table 25 and Table 26. (*For the sources of the BIM requirements, see Appendix I.*)

Table 25. BIM requirements for BIM scenario 1

#	Requesting party	Supplying party	BIM requirement
A1	Prime contractor	Client/ Designer	<u>3D model/ design</u> A 3D design model is an important basis for all of the BIM scenarios for construction logistics. In traditional contracts (Design-Bid-Build), it is possible that the client will not supply a 3D model to the prime contractor. In this case, the prime contractor would have to develop the 3D model from the 2D drawings himself. This can prevent the prime contractor from applying BIM scenarios for construction logistics in a project. It is also possible for the client to supply a 3D model to the prime contractor. During the tender phase, the model serves as a design intent model, showing the architectural and engineering intentions of the designers. For renovation projects, the client can also supply the 'As-maintained' 3D model of the facility to the prime contractor. The as-maintained 3D model reflects all the maintenance activities and any changes made to the facility during the operation and maintenance phase in the model. When the client supplies a 3D model to the prime contractor, the **client should ensure that the 3D model is correct and reliable**. Furthermore, the client should ensure that the 3D model was produced using standardized processes and agreed standards and methods, which the client should report in an accompanying BIM protocol. This enables the information in the 3D model to be used and reused by the prime contractor. On the other hand, if the client waives responsibility and liability, then the prime contractor needs to invest time and resources to check the reliability of the model and eventually correct the errors in the model.
A2	Subcontractors/ suppliers	Prime contractor (Designer in case of integrated contracts)	<u>3D model as basis for engineering and production</u> Generic BIM requirements for subcontractors and suppliers to enable the use of 3D model as basis for developing production models are detailed by Eastman et al. (2011, pp. 328-333). Information that should be included in the model are **3D geometry, material specifications, finishing requirements, and delivery sequence**. Another requirement is the ability to group components according to criteria specified by subcontractors and suppliers on the basis of their geometric information and order of assembly to manage production, procurement of parts and shipping. For this, the prime contractor (or designer, in the case of integrated contracts) would have to invest time and resources in an earlier phase of the project to develop the model for its use and reuse by project partners later on in the project. Agreements must be made between the involved parties regarding the distribution and compensation of the BIM activities.

Continuation of Table 25. BIM requirements for BIM scenario 1

<table>
<tr><th>#</th><th>Requesting party</th><th>Supplying party</th><th>BIM requirement</th></tr>
<tr><td>A3</td><td>Prime contractor</td><td>Subcontractors/ suppliers</td><td>3D production model
Specialist subcontractors and suppliers should deliver 3D production models to the prime contractor for (partly automated) control of clashes and other errors.</td></tr>
<tr><td colspan="4">Additional requirement (in the case of integrated contracts)</td></tr>
<tr><td>A4</td><td>Prime contractor</td><td>Designer</td><td>3D model/ design
In integrated contracts, the prime contractor can contract the designer to produce a 3D model of the design. For this, the prime contractor and designers must agree on terminologies, standard procedures and modeling agreements. Access rights and permissions based on each participant's role and responsibilities should be setup as well.

The scoping of the data exchange using BIM is also critical for its application. Additional agreements should also be made regarding coordination and model management, to manage and resolve clashes, model conflicts and object duplication.

For the prime contractor to be able to use the 3D model for logistics, the designer should produce the following information (Eastman et al., 2011, p. 269):
- Detailed building information, which provides graphical views of the facility's components comparable to those shown in typical construction drawings for the prime contractor to generate and extract information (such as quantity and component property information). This data is needed for procurement, installation, and commissioning.
- Analysis data related to performance levels and project requirements, such as "structural loads, connection reactions and maximum expected movements and shear, heating and cooling loads for tonnage of HVAC systems, … and the like". This data is needed for procurement, fabrication, and MEP detailing.

This information would be used by the prime contractor, subcontractors and suppliers downstream the construction process. The prime contractor should consider how to adequately motivate the designer to produce the 3D model that can be (re)used downstream the construction process.</td></tr>
</table>

Table 26. BIM requirements for BIM scenario 2

#	Requesting party	Supplying party	BIM requirement
B1	Prime contractor	Client/ Designer	3D model/ design Equal to BIM requirement #A1 (see Table 25)
B2	Prime contractor	Subcontractors/ suppliers	Project status and procurement tracking Each component can have a field named "Status". Values may be "approved for construction review", "in fabrication", "in delivery", and so forth, which can be associated with colors to quickly determine the status of the facility and identify bottlenecks or areas that are behind schedule. For this, subcontractors and suppliers have to supply data on the **status and location of services and materials**. This can be achieved by linking GPS technologies and RFID tags with the 3D/4D model.
B3	Subcontractors/ suppliers	Prime contractor	4D model **Visualization of detailed planning** of a construction operation, to pull delivery of prefabricated parts to the construction site in a just-in-time arrangement. This includes a building model and a model of temporary facilities and cranes for a step-by-step planning and simulation of the installation sequence. The subcontractors and suppliers should also have **access to up-to-date 4D model**, to check the status of activities and eventually adjust the schedule of deliveries according to the progress of work on site.
Additional requirements (in the case of integrated contracts)			
B4	Prime contractor	Designer	Level of detail and decomposition of objects In addition to BIM requirement #A3 (see Table 25), Eastman et al. (2011, pp. 290-292) lists BIM requirements for preparing and developing a 4D model: - **Model scope and level of detail** – to develop a 4D model of a detailed schedule, then the 3D model should also be developed into a higher level of detail. - **Decomposition and aggregation** – planners should be able to decompose and aggregate objects into portions to show how they will be constructed. The designer should align the production of the 3D model with the needs of the planner early on in the design phase. Since the above activities are not traditionally conducted by designers, agreements must be made between the prime contractor and designers regarding possible compensation schemes.
B5	Prime contractor	Client	Data on existing road networks Model of existing road networks, with data on capacity and estimated use of existing road network, which the prime contractor can use as basis for analyzing the effects of alternative construction phase planning on traffic.
B6	Client	Prime contractor	4D model 4D model demonstrating the effects of planned construction activities and risk mitigation strategies on traffic and availability of public and temporary roads during the execution phase.

3.2 Design of the incentives for applying BIM scenarios for construction logistics

In this section, the design of Product 2: Incentives for applying BIM uses for construction logistics will be discussed. This section is structured into two subsections. First, the functional requirements that the incentives must fulfil will be given (subsection 3.2.1). Second, the design of the incentives for applying BIM uses for construction logistics will be discussed (subsection 3.2.2).

3.2.1. Functional requirements for the incentives

By itself, the benefits of BIM scenarios for construction logistics could motivate organizations to apply them in a project. However, these benefits may not always be equal among the participating organizations. The difference in benefits could lead to a difference in interest to use BIM. Additional incentives are therefore important to positively influence the choice of an organization to apply BIM scenarios for construction logistics in a project. Therefore, the main function of product 2 is to ***propose incentives*** for applying BIM uses for construction logistics in a project.

As determined from the problem investigation, a necessary step in designing effective incentives is to ***define the needs and goals*** of an individual or an organization. These are specified in the BIM scenarios for construction logistics. The needs and goals of an organization are also defined by what the organization should contribute/ deliver for the application of the BIM scenario and what the organization could eventually gain from that application. The distribution between the required input from and the potential benefits for each organization are also specified in the BIM scenarios for construction logistics.

Once the needs are defined, the next function is to ***describe the incentive***, by indicating the collaboration setting and relationship for which the incentive is applicable, and describing how the incentive works. Last, the content of the incentive should include the ***suggested application***: how the incentive should be applied to effectively motivate organizations to apply BIM scenarios for construction logistics in a construction project. For this, it is important that the awarding criteria motivate the contracted organization to test the effectiveness of its proposed solutions. The functional requirements for the incentives are illustrated in a FAST diagram (see Figure 14).

3.2.2. Design of the incentives

To design the incentives, each functional requirement discussed above should be filled in. Each resulting incentive for applying BIM scenarios for construction logistics should therefore contain the following items:

1) Define needs: connect BIM scenario for construction logistics, which specify the needs and goals of each organization, and the distribution of required input from and potential benefits for each organization
2) Describe incentive: indicate applicable collaboration setting and relationship, and describe how the incentive works
3) Suggest application: specify awarding criteria and provide an example.

As determined from the problem investigation phase, sharing of savings, and MEAT criteria related to BIM and construction logistics are chosen to be further developed. These two incentives were viewed both as the most important and effective incentives for motivating organizations, and as the most feasible incentives to be applied in a specific project to motivate organizations to apply BIM scenarios for construction logistics. The two developed incentives for applying BIM scenarios for construction logistics, which contain the three items mentioned above, are presented in Table 27 and Table 28.

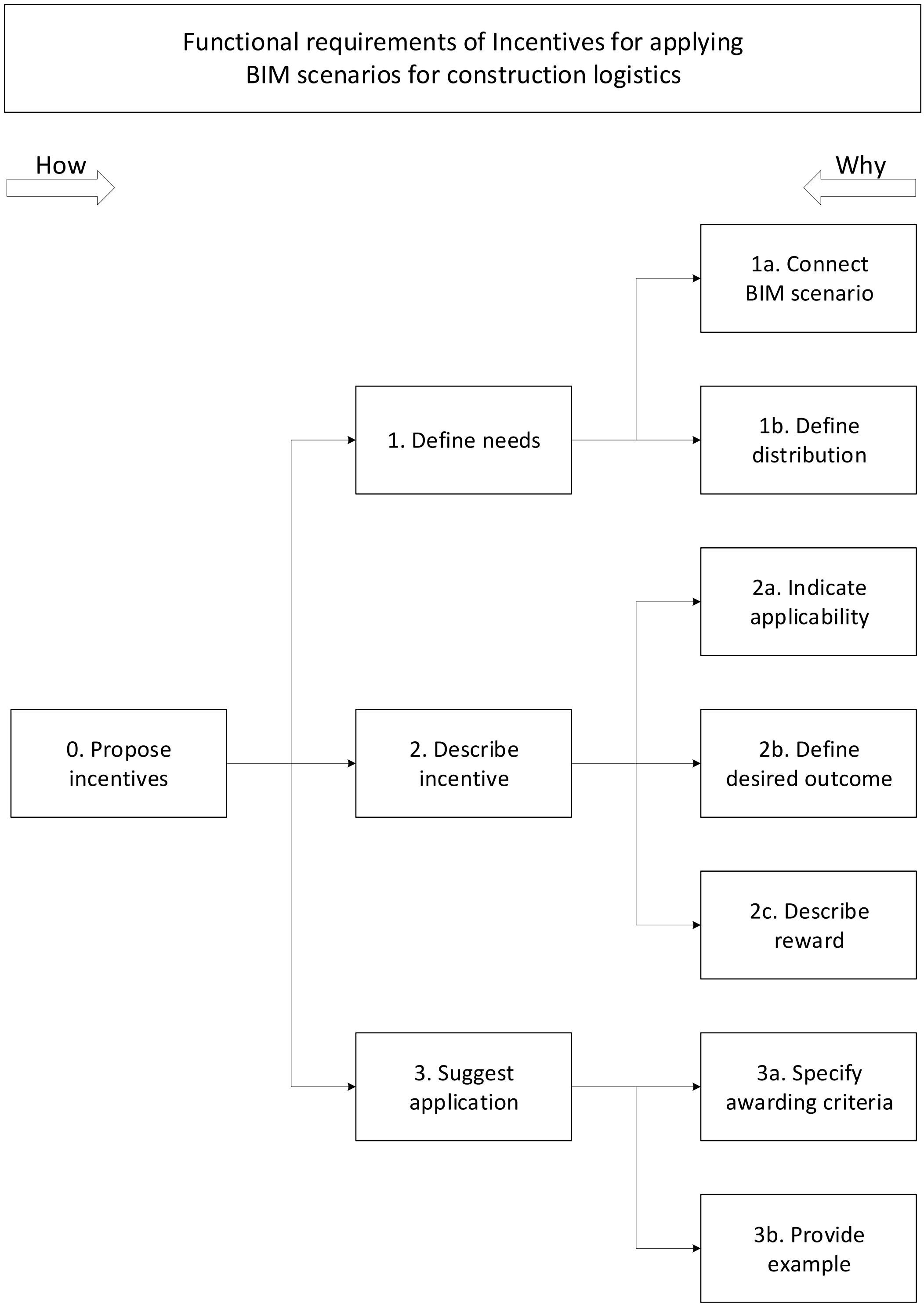


Figure 14. FAST diagram for Product 2: Incentives for applying BIM scenarios for construction logistics.

Table 27. Incentive #1: Sharing of savings

1. NEEDS & GOALS OF ORGANIZATIONS
Based on the descriptions of the BIM scenarios for construction logistics, it is found that the client, prime contractor, designers, subcontractors and suppliers need to participate in the application of the BIM scenarios and deliver information for the successful use of the scenarios. However, the potential benefits of the BIM scenarios for construction logistics is not equal for all these organizations. The differences in potential benefits may result to differences in motivation to apply BIM scenarios for construction logistics in a project. To motivate organizations to apply BIM scenarios for construction logistics in a project, additional incentives can be applied.
2. INCENTIVE: SHARING OF SAVINGS
Prime contractors, designers, subcontractors and suppliers can be incentivized to perform better using BIM by sharing the savings generated from the use of BIM scenarios for construction logistics. When savings are shared among these organizations, then they are motivated to apply BIM scenarios to reduce errors in the design and to optimize design and logistics. This incentive is applicable to the ***1st layer and 2nd layer relationships***, within ***integrated collaboration settings***. Integrated collaboration settings provide a very suitable basis for sharing of savings, since they provide a judicial framework from which parties can model their contract. In addition, they allow for the early and close involvement of parties (i.e. involvement during the design phase and ability to influence the design), which is necessary for parties to influence and optimize the design (RRBouw, 2004).
3. SUGGESTED APPLICATION
One way to (generate and) share savings using BIM scenarios for construction logistics is through the principle of value engineering. During contract formulation, organizations can agree to apply value engineering and stipulate in their contract a percentage of distribution of savings. During the design phase, the prime contractor (possibly with input from subcontractors and suppliers) formulates measures/strategies to optimize design and logistics. The prime contractor could pay the designer for the BIM activities related to these strategies (such as adjusting the BIM model, and/or adding information to the model). In addition, actual savings realized by the prime contractor during the execution phase resulting from these strategies will be shared with the designer (according to a predetermined percentage of distribution). This would motivate the designer to ensure that the BIM model is created in a manner that it could be used to realize the savings (during the execution phase). For example, the prime contractor has thought of a logistics optimization strategy that will save him €200.000. However, this strategy requires that the design model has to be adjusted and that attributes are to be added in the model. Adjusting the design model and adding the attributes would cost €120.000 for the designer. For the project, this would mean a savings of €80.000. The prime contractor pays the designer €120.000 for the BIM services. When the savings of €80.000 are actually realized, then the savings would be distributed among the prime contractor and the designer (according to a predetermined percentage of distribution). *Footnotes:* Sharing of savings requires transparency and trust from both parties. The organizations have to be transparent in the costs and savings they (will) incur, and they have to trust each other that these costs and savings are accurate.

Table 28. Incentive #2: MEAT criterion 4D BIM & construction logistics

1. NEEDS & GOALS OF ORGANIZATIONS
BIM scenario #2 (4D modeling) could support construction logistics optimization and minimize nuisance to traffic caused by construction activities during the execution phase. For this, the prime contractor should deliver a 4D model to the client in the tender phase.
2. INCENTIVE: MEAT CRITERION 4D BIM & CONSTRUCTION LOGISTICS
The MEAT (most economically advantageous tender) criteria are a set of criteria used to compare bids and to determine the winning bid. Instead of comparing the bids on the basis of lowest price alone, bids are compared on the basis of both quality and price. The use of the MEAT criteria could increase the motivation of the prime contractor to think of the objectives of the client for a better chance of being awarded the contract (PIANOo, 2014a). The MEAT criterion 4D BIM & Construction logistics is aimed to motivate the prime contractor to optimize logistics and to minimize nuisance to traffic using 4D BIM. This incentive is applicable to the ***1st layer relationship (client – prime contractor)***, and can best be applied in ***integrated contract*** projects, wherein the prime contractor has the possibility to influence design and optimize construction logistics. This incentive influences the personal and external motivation of the prime contractor to apply 4D modeling in a project. External motivation is influenced because 4D modeling is prescribed by the client. Personal motivation is influenced by three potential benefits (related to this incentive) of 4D modeling perceived by the prime contractor: 1) 4D modeling supports the prime contractor in optimizing logistics 2) 4D modeling supports the prime contractor in developing (more) effective strategies for mitigating the risk of nuisance to traffic 3) 4D modeling supports the prime contractor in proving and demonstrating the effectiveness of his logistics plan and risk mitigation strategies These benefits of 4D modeling increase the chance of the prime contractor in winning the tender, and therefore positively influences his personal motivation to apply 4D modeling in a project.
3. SUGGESTED APPLICATION
The suggestions presented in this report supplement the guidebook of Taskforce Doorstroming (2009). Taskforce Doorstroming (2009) (which includes Bouwend Nederland, Rijkswaterstaat, ANWB and ProRail) has released a guidebook for project managers, contract managers, environment managers, traffic advisers and purchasing advisers of clients and prime contractors on how to effectively formulate and apply a MEAT criterion for minimizing nuisance to traffic. This report adds to the guidebook suggestions on how to link 4D modeling to the MEAT criterion.
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3. SUGGESTED APPLICATION – CONTINUATION

Goals for linking 4D modeling to the MEAT criterion Construction logistics:

The goal of linking 4D models to the MEAT criterion Construction logistics is to steer the prime contractor to optimize construction logistics and minimize nuisance to the public during the execution phase. The linking of 4D models contributes to this goal by:

- Forcing the prime contractor to thoroughly think about and work out his MEAT strategies using 4D modeling
- Supporting the prime contractor in proving and demonstrating the effectiveness of MEAT strategies
- Supporting the client's tender and evaluation committee in understanding the (effects of) proposed MEAT strategies and consequently be more able to steer the prime contractor to the desired effects

General requirements on the 4D model:

In relation to file formats, the client is advised to prescribe open file formats for exchanging 3D models and 4D models. The table below gives an example of file formats for each file type, which the client can use for prescription.

File type	Editable format	Read-only format
Text	DOC Word	PDF/A
4D model	NWD, SPX	NWD, SPX
3D model	IFC, RVT, LandXML	IFC, DWG, DXF, DWF, 3D PDF
Schedule	MPX, PLF, XER	PDF/A
Photo	TIFF	PDF/A, JPG, TIFF
Video	Mpeg	

Content of the 4D model:

The contents of the 4D model should be aligned with other documents submitted by the prime contractor. For example, phase planning drawings and schedules submitted by the prime contractor for the tender should be in accordance with the information in the 4D model. Furthermore, the client should define specific objects related to construction logistics, together with the corresponding Level-of-Development (LOD), that the client requires to see in the 3D/4D model. Example of objects that should be included in the model are:

1) Volumes/ space reservations for objects and planned work spaces, linked with construction phase planning
2) Existing and temporary roads connected to or in the nearby surroundings of the construction site, possibly with a link to a planning when the roads will be (partially) closed

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Continuation of Table 28. Incentive #2: MEAT criterion 4D BIM & construction logistics

3. SUGGESTED APPLICATION – CONTINUATION
Content of the 4D model: In addition to the 4D model itself, the prime contractor could be requested to submit a BIM Protocol/Execution Plan, which details the following aspects (Hogeschool van Amsterdam, 2015): 1) Organization and method (after award) a) Describe your BIM team structure (organization chart with disciplines, functions, responsibilities and delegation lines). b) How do you ensure integration of 3D and 4D BIM in your project organization? c) Describe your BIM process (process diagram in which the relationship between disciplines and activities is shown in outline, mirrored to the project information process diagram). 2) Data management (after award) a) Are all BIM data recorded in a similar structured way? b) Are BIM standards used for the exchange of data? c) How is the actuality of BIM data guaranteed? d) How is the quality of the BIM data monitored? 3) Supply chain management (after award) a) Which criteria in relation to BIM are used when selecting subcontractors and suppliers? b) How are BIM data shared among project partners? c) How are the subcontractors and suppliers involved in the BIM process? *Evaluation of the 4D model:* The submitted 4D models and accompanying BIM Protocol/Execution Plan should be evaluated in connection with the MEAT strategies. The prime contractor will earn points/fictional price reductions if the submitted 4D models demonstrate the effectiveness of the MEAT strategies. The effectiveness of the MEAT strategies could be evaluated based on the following four criteria (see Taskforce Doorstroming (2009) for further information on these criteria): 1) Degree of nuisance (*hinderklasse*) 2) Category of nuisance (*hindercategorie*) 3) Duration of nuisance (*hinderperiode*) 4) Risk of delay *Footnotes:* In applying the MEAT criterion 4D BIM & construction logistics, the client should consider both the effort required from the prime contractor to develop his risk mitigation strategies, and the effort required from the client's tender evaluation committee to judge the submitted risk mitigation strategies. The former could be reduced by: 1) Considerable input from the client – the client could provide the prime contractor with information such as traffic simulation models, and estimated capacity & use of existing road networks 2) Innovative procurement methods – the client could make use of innovative procurement methods, wherein the client and a preselected prime contractor enter into a collaboration to explore possible solutions to complex problems. Through this collaboration, tender costs for both parties can be minimized.
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The two incentives for applying BIM scenarios for construction logistics presented above will be validated in the next phase, treatment validation (Chapter 4). Any changes to the incentives resulting from the validation phase will be discussed in the next chapter, subsections 4.2.2 and 4.4.2.

3.3 DESIGN OF THE ADDENDUM TO THE BIM PROTOCOL

In this section, the design of Product 3: Addendum to the BIM protocol will be discussed. This section is structured into two subsections. First, the functional requirements that the addendum must fulfil will be given (subsection 3.3.1). Second, the design of the addendum to the BIM protocol will be discussed (subsection 3.3.2).

3.3.1. Functional requirements for the addendum

As discussed in the previous section, incentives are important to positively influence the choice of an organization to apply BIM scenarios for construction logistics in a project. It is also important that organizations are kept to the terms of these incentives. This can be achieved by anchoring the incentives to the contract. Therefore, the main function of the addendum to the BIM protocol is to ***anchor the incentives*** to the contract. For this, the addendum should ***stipulate which BIM scenarios for construction logistics*** will be applied in the project, ***stipulate the BIM requirements*** that correspond to the chosen BIM scenarios for construction logistics, and finally, ***stipulate the incentives*** that are linked to the BIM requirements. The functional requirements of the addendum are illustrated in a FAST diagram (see Figure 15).

Some of the incentives can be stipulated in the contract itself. However, these incentives should still be linked to the BIM-related agreements, which are stipulated in the BIM protocol. For example, agreements regarding sharing of savings are stipulated in the contract itself. However, the BIM requirements and activities of organizations in relation to achieving the savings should be stipulated in the BIM protocol.

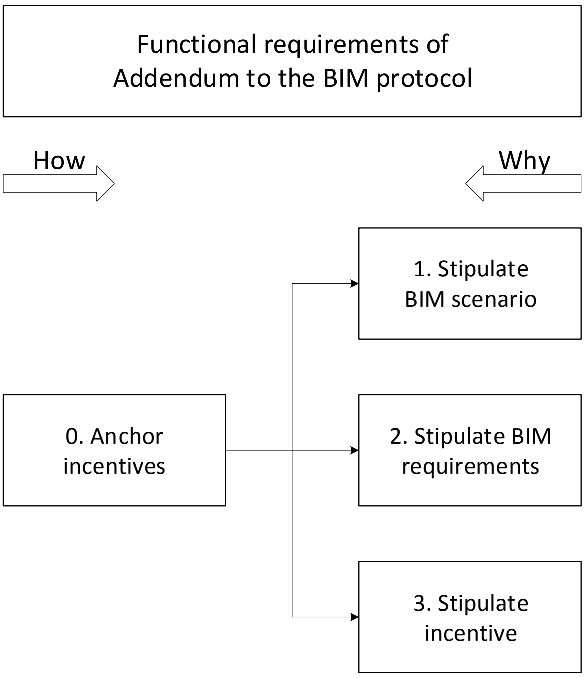


Figure 15. FAST diagram for Product 3: Addendum to the BIM protocol.

3.3.2. Design of the addendum to the BIM protocol

Based on the functional requirements described above, the PDEng trainee created an addendum to the BIM protocol. For this, the PDEng used the *Nationaal Model BIM Protocol* (BIR Werkgroup BIM Protocol, 2016a) and *Nationaal Model BIM Uitvoeringsplan* (BIR Werkgroup BIM Protocol, 2016b) as templates. Furthermore, the PDEng trainee developed the addendum in alignment with the information delivery scheme for the use of 4D BIM, for which a conceptual design was also developed by the PDEng trainee (see Appendix N). The resulting addendum (in Dutch) is presented in the next page.

Addendum bij het BIM Protocol

1. Introductie

1.1. Doel en scope van het addendum

Doel van dit addendum is om succesvolle toepassing van BIM voor inkoop en bouwlogistiek in de <*fasen…*> van het project <*projectnaam*> te borgen. In dit addendum zijn afspraken vastgelegd die de partners hebben gemaakt (en nog zullen maken) om te voldoen aan de informatiebehoeften in relatie tot inkoop en bouwlogistiek. De levermomenten en bijbehorende informatiebehoeften zijn gedefinieerd in hoofdstuk 3 van dit addendum *(dataoverdrachtschema)*.

De afspraken, eisen en aanbevelingen uit dit addendum zijn van toepassing voor alle partijen die betrokken zijn bij het produceren, gebruiken, controleren of raadplegen van BIM-informatie binnen het project, inclusief de opdrachtgever en eventuele gebruikersorganisaties.

1.2. Status van het addendum

Het addendum is gerelateerd aan de contractuele bepalingen met betrekking tot BIM en maakt deel uit van het BIM Protocol c.q. het BIM Uitvoeringsplan. Bij eventuele discrepanties tussen het addendum en de contractdocumenten, prevaleren de contractdocumenten.

2. BIM scenario's voor inkoop en bouwlogistiek

2.1. Behoeften in relatie tot inkoop en bouwlogistiek

In dit project zal de BIM scenario's voor inkoop en bouwlogistiek worden ingezet voor (voorbeelden):

Ontwerpfase

- Afstemmen van deelontwerpen van verschillende partijen/disciplines met elkaar om ontwerpfouten te minimaliseren en daardoor minder verstoringen in het uitvoerings- en logistieke proces
- Consistente verwerken van veranderingen in het ontwerp om fouten in tekeningen te minimaliseren en daardoor minder verstoringen in het uitvoerings- en logistieke proces
- Analyseren en vergelijken van de effecten van alternatieve bouwfaseringen op verkeerstromen en beschikbaarheid van publieke en tijdelijke wegen
- Optimaliseren van bouwmethode en bouwvolgorde (en eventueel optimaliseren van het ontwerp)
- …

Werkvoorbereidingsfase

- Duidelijk visualiseren en communiceren van de locatie, context en hoeveelheden van specifieke elementen met bepaalde specificaties/ wat, waar en hoeveel (inkoopdemarcatie)
- Zelf genereren en gebruiken van informatie uit het ontwerp
- Afstemmen (samenvoegen en controleren) van productiemodellen van verschillende partijen/disciplines met elkaar om ontwerpfouten te minimaliseren en daardoor minder verstoringen in het uitvoerings- en logistieke proces
- Bekijken van het ontwerp vanuit elk mogelijk gezichtspunt en op verschillende momenten tijdens het uitvoeringsproces om inzicht te krijgen in uitvoeringsomstandigheden
- Bepalen wat, wanneer en hoeveel geleverd moet worden
- …

Uitvoeringsfase

- Monitoren of bestellingen op tijd geleverd worden en gevolgen van levertijd op activiteiten zien
- Beheren van voorraad op de bouwplaats
- Op detailniveau afstemmen wie, waar activiteiten uitvoert
- Optimaliseren gebruik van ruimte op de bouwplaats
- …

2.2. Oplossingen (BIM scenario's voor inkoop en bouwlogistiek)

Om de behoeften in relatie tot inkoop en bouwlogistiek te kunnen vervullen, zal BIM worden ingezet voor (voorbeelden):

1. Uitwisseling gegevens met andere projectpartners/ projectdisciplines

- ☐ Maken van een 3D-model per ontwerpende discipline
- ☐ Integreren 3D-modellen van ontwerpende disciplines
- ☐ Maken van een 3D-productiemodel per leverancier
- ☐ Integreren 3D-ontwerpmodel en 3D-productiemodellen
- ☐ Controleren modellen op raakvlakknelpunten of andere fouten
- ☐ Genereren van 2D-tekeningen uit het 3D-model
- ☐ Filteren en zoeken op elementtype of parameter
- ☐ …

2. Koppeling 3D-model aan een planning (4D-model/bouwfasenplanning)

- ☐ Maken van een 3D-model per ontwerpende discipline
- ☐ Maken van een 3D-model van tijdelijke hulpconstructies en kranen
- ☐ Integreren 3D-modellen en koppelen aan een planning (productie, leverings- en/of uitvoeringsplanning)
- ☐ Gebruiken viewpoints en tags tijdens het navigeren in het 4D-model om inzicht in uitvoeringsomstandigheden te krijgen
- ☐ Visualiseren en optimaliseren van bouwactiviteiten op het kritieke pad
- ☐ Gebruik 4D-model om aan te geven waar en wanneer hinder op publieke en tijdelijke wegen plaatsvindt
- ☐ Koppeling van BIM met verkeersmodellen
- ☐ Koppeling van BIM met GIS
- ☐ Gebruik 4D-model om tijdstip en status van voorbereiding, productie, levering en uitvoering per object te monitoren
- ☐ Koppeling model met draadloze technologie zoals barcodes of RFID-tags op de bouwplaats
- ☐ Inzichtelijk maken in het model waar onderdelen zich bevinden
- ☐ Gebruik bouwmodel om status van de onderdelen, bijvoorbeeld 'in productie' of 'in opslag' te zien
- ☐ Gebruik 4D-model voor grafische weergave van permanente en tijdelijke voorzieningen op de bouwplaats, inclusief een planning van bouwactiviteiten
- ☐ Managen van opslagterrein, toegang tot de bouwplaats, plaatsing van tijdelijke voorzieningen en groot materieel (bijvoorbeeld kranen)
- ☐ …

3. Dataoverdrachtschema

Om de oplossingen te kunnen verwezenlijken, hebben de projectpartners voor dit project afgesproken om de volgende informatie met elkaar te delen (voorbeelden):

Informatie	Vragende projectpartner	Leverende projectpartner	LOD	Datum/ periode	Data-formaat
Verkeersmodellen van bestaande wegen	Hoofdaannemer	Opdrachtgever	-	Tenderfase	-
4D model	Opdrachtgever	Hoofdaannemer	LOD200	Tenderfase	NWD en SP
3D ontwerpmodel	Onderaannemers/ Leveranciers	Hoofdaannemer/ Ontwerpers	LOD300	Werkvoorbereidingsfase	IFC en DWG
3D productiemodel	Hoofdaannemer	Onderaannemers/ Leveranciers	LOD400	Werkvoorbereidingsfase	IFC en DWG
4D model	Onderaannemers/ Leveranciers	Hoofdaannemer	LOD400	Werkvoorbereidingsfase en Uitvoeringsfase	NWD en SP
Voortgang van activiteiten	Hoofdaannemer	Onderaannemers/ Leveranciers	-	Uitvoeringsfase	-
…					

4. Gekoppelde afspraken

De bovenstaande BIM-uitwisselingen zijn (deels) gekoppeld aan contractuele bepalingen met betrekking tot betalingsregelingen overeengekomen in <*Artikelnummer of Bijlagenummer*> van de basisovereenkomst.

3.4 CONCLUSIONS ON THE TREATMENT DESIGN

In this chapter, the three design products were presented. Based on the results of the investigation phase, conceptual designs of the three products were developed. The validation of these products will be discussed in the next chapter (Chapter 4).

Product 1: BIM scenarios for construction logistics – From the problem investigation, it was found that there is a need to make the potential benefits of BIM specifically for construction logistics more explicit to clients, prime contractors, designers, subcontractors and suppliers in various collaboration settings. In this chapter, two BIM scenarios for construction logistics were designed. The BIM scenarios link BIM with construction logistics by reporting its benefits for construction logistics in a project with a traditional or an integrated contract type.

Product 2: Incentives for applying BIM scenarios for construction logistics – From the problem investigation, it was found that there are possible incentives that can be applied to motivate the use of BIM, but there were no incentives that are designed specifically for the use of BIM for construction logistics. In this chapter, two additional incentives for applying BIM scenarios for construction logistics in a project were designed. They provide recommendations for contracting organizations (client or prime contractor) to motivate other organizations to use BIM in a project, with the aim of optimizing construction logistics.

Product 3: Addendum to the BIM protocol – From the problem investigation, it was found that existing reviewed BIM protocols do not contain agreements specific to BIM uses for construction logistics or to incentives for applying BIM uses for construction logistics. In this chapter, such agreements were designed, which resulted to the addendum to the BIM protocol. The addendum contains agreements regarding the delivery of information needed for the BIM scenarios for construction logistics and the incentives linked to the BIM scenarios.

Chapter 4. Treatment validation

In Chapter 3, three new products were presented. In this chapter, it will be evaluated whether the three products satisfy the requirements. For this, two rounds of validation were conducted. In the first round, product 1 (BIM scenarios for construction logistics) and product 2 (incentives for applying BIM scenarios for construction logistics) were evaluated through a Technical Action Research (TAR). In the second round, all three products (including the addendum to the BIM protocol) were evaluated by expert opinion.

This chapter is structured as follows. The first round of validation, which is the technical action research, will be discussed in section 4.1. This is followed by the presentation of the changes made to the products, based on the first round of validation, in section 4.2. The second round of validation, which is expert opinion, will be discussed in section 4.3. This is followed by the presentation of the changes made to the products, based on the second round of validation, in section 4.4.

"Reason only knows what it has succeeded in learning."

-Fyodor Dostoevsky, Notes from Underground, White Nights, The Dream of a Ridiculous Man, and Selections from The House of the Dead

4.1 VALIDATION: TECHNICAL ACTION RESEARCH

As described in subsection 1.2.2, the first step in the treatment validation phase is a technical action research (TAR). TAR was performed in the tender phase of the infrastructure project New Lock Terneuzen. The description of the project New Lock Terneuzen, including the observation moments, conducted interviews, and reviewed documents can be found in Appendix F.

In the following subsections, the execution of the TAR and the evaluation of the products will be discussed. The application of the PDEng design products to the case study will be discussed in subsection 4.1.1, followed by the evaluation of their application in subsection 4.1.2.

4.1.1. Application to the New Lock Terneuzen

The client's tender team had the ambition to implement 3D BIM during the tender phase and also during the realization of the project. The motivation of the client to request 3D BIM was to gain insight into the RAMS (reliability, accessibility, maintainability, and safety) aspects using the 3D model. The client also decided to include 4D BIM in the request. The objective of the client in requesting 4D BIM was to use the 4D model during the competitive dialogue as:

1) a communication tool
2) for coordinating between the client and the prime contractors regarding the design
3) to validate the products submitted by the prime contractors for the MEAT criteria, specifically the two MEAT criteria on risk of delay and nuisance to shipping traffic

For defining the 4D BIM requirements, the client instituted a 4D evaluation committee, which supported the client with the 3D and 4D BIM request and advised the client in the formulation of the request.

The PDEng trainee was a member of the 4D evaluation committee. Also, the trainee's industry supervisor was a member of the same committee. Both the trainee and the supervisor performed the roles of consultant and researcher in the TAR. Throughout the TAR, the trainee and supervisor compared and discussed their findings. This process helped ensure the internal validity of the findings, by minimizing researcher's bias. The resulting application of the BIM scenario and incentive will be discussed next.

4.1.1.1. Application of BIM scenario #2: Coupling of 3D model to a planning

Before defining the 4D BIM requirements, the client first had to determine specifically how BIM could be used to support the competitive dialogue, with the aim of minimizing the risk of delay and nuisance to shipping traffic. For this, the client's tender team discussed with the PDEng trainee and the supervisor regarding their logistics requirements:

1) See when the prime contractor plans to close a road
2) Determine how much construction related traffic is expected for each construction phase (volume and direction) and its effect on public and temporary roads
3) Determine (and evaluate) which areas are considered by the prime contractor as important risks

Based on the logistics requirements of the client, the PDEng trainee suggested two BIM uses, which could be applied to the project:

1) 3D modeling/ designing
2) BIM scenario #2: Coupling of 3D model to a planning (4D modeling)

BIM scenario #2 was further developed to the specific details of the project. This resulted to the definition of elements that should be visualized in the model. These elements are:

1) Bridge:
   a) Accessibility (e.g. simple way for replacing and storing cylinders)
   b) Free space profile for conserving and inspecting the bridge (e.g. availability of below elevation platform)
   c) Spatial quality and design linked to RKV plan (Spatial quality and design plan)
2) Canal gate:
   a) Accessibility (e.g. simple way for replacing and storing the upper and lower track rollers)
   b) Free space profile for in-situ conserving and inspecting the gate (inside and outside)
   c) Design and operation and maintenance of the midpoint conductor
3) Terrain layout:
   a) Space usage (space for contractors) and link with the aesthetic program of requirements for crane zones, cable lines, levelling valves, sewage, cellars, manholes, green areas, roads, fences, safety zones, and service roads over the canal gates
   b) Integrality (e.g. taking into account possible nuisance during maintenance activities)
   c) Access and connections to public roads and access facilities
   d) Firefighting facilities (pump room, electricity facilities, and connections FIFI)

4.1.1.2. *Application of incentive #2: MEAT criterion 4D BIM & construction logistics*

The requirement for submitting 4D BIM was formulated in the latter half of the competitive dialogue. As a result, it was too late to link the 4D BIM requirement with the MEAT criteria, which the client already announced in the first half of the competitive dialogue. In addition, due to legal reasons, it was decided not to request the 3D and 4D models as validity products. Instead, it was decided to limit the request to critical parts of the design and the construction phasing, and to request 4D BIM as an additional tender document that the prime contractors have to submit.

The resulting requirement can be found in Appendix G (in Dutch). Additional clarifications regarding the 4D BIM requirement are given in Table 29, based on the questions of the three competing prime contractors.

Table 29. Points of concern with the 4D BIM request.

Points of concern of the prime contractors	Client's response
LOD-300 is not feasible during the tender phase. What is the background of LOD-300? Does this apply to all parts (e.g. ladders, bollards, handrails, etc.)? In addition, a LOD-300 for the site layout is too high for the tender phase.	Focus is on risk and functionality. LOD-300 means reliable in quantity, size, shape, location and orientation. Items that, according to the candidate, are part of the critical aspects of the project should be worked out on LOD-300. Other parts may be worked out at a lower level of detail.
What is the client's expectation about the level of detail of the 4D model? E.g. does the client want to visualize every concrete pour in the model? The requested LOD level is too high because a high detail of the planning is often not achieved during the tender.	The client expects that the 4D model will show the critical aspects of the project and will convince them that the candidate is able to realize the plan successfully. The detailing is partly determined on the basis of the risk assessment of the candidate.
The client wishes to see the traffic directions and intensities in the model for each construction phase. These are practically unfeasible to model. In addition, one of the candidates indicated that making a 4D model during the tender phase has no added value for the candidate and is more like extra work.	The client does not want to burden the candidates with extra work. The client indicates that it is not the intention to see beautiful visualizations of which it is not clear where the bottlenecks lie and where/ when control measures have been taken. In the tender, it is more about interpretation than about detailing. The objective with respect to communication is leading.

4.1.2. Evaluation by the client and three competing prime contractors

The application of BIM scenario #2 and incentive #2 were evaluated by the client and the three competing prime contractors.

4.1.2.1. Evaluation of BIM scenario #2

For the client, the use of the 4D model alone did not satisfy the logistics requirement: "Determine how much construction related traffic is expected for each construction phase (volume and direction) and its effect on public and temporary roads". By itself, the 4D model could not visualize or demonstrate how much vehicle hours are lost (or *voertuigverliesuren* in Dutch) for each construction phase, for example.

For the prime contractors, all three were of the opinion that 3D modeling is certainly valuable during the tender phase. By making and using 3D modeling, they can guarantee the integral coherence of the design. In addition, they use the 3D model to generate quantities for cost calculation and planning. BIM is always represented in the project team for large construction projects, where multidisciplinary work is being carried out.

Two of the three prime contractors indicated that the use of 4D BIM during the tender phase had added value for them. The candidates used the 4D model to work out detail solutions and not necessarily to optimize their building phases. Both building consortia also apply 4D BIM in the tender for other projects. The added value of 4D BIM lies in the integration of different disciplines and the possibility to be able to navigate and visualize in the model on different perspectives and on different construction phases. This gives the members of the tender or project team the same perspective and they can better understand the situation.

For one of the three prime contractors, **the use of 4D BIM during the tender phase contributed to a significant reduction of nuisance on shipping traffic.** First, the prime contractor used Synchro Pro to support the development of the core strategy. Four variants of the design for the outer gate head, anchor pilings, and temporary foundations were modelled. Various sequences of constructing and demolishing the temporary foundations and anchor pilings were loaded in Synchro Pro. The 4D model has helped to come up with the sequence of the foundations, when anchors can be removed because the sluice plateau is made and when the anchors have to stay because the passage channel is still there. The prime contractor's tender team could navigate in various time periods and in various arbitrary viewpoints using the 4D model. In an iterative process supported by the 4D BIM tool, the tender team could explore which combinations of the design variants and construction/demolition sequences would keep the middle lock operational for the longest period. This process resulted to the best alternative with which the Middle Lock could be kept open as long as possible.

Second, the prime contractor also used Synchro Pro to check the completeness of the 3D model and the construction schedule. Activities as well as objects that were not linked to any object and any activity, respectively, were identified by the BIM manager, who then notified either the planner or the designer. This increased the robustness of the schedule, which mitigated the risk of delay to project completion, and consequently, the risk of prolonged nuisance.

Last, the use of the 4D BIM tool allowed for efficient testing of the feasibility of the strategies. The prime contractor could visually inspect the 4D model for design and workflow clashes, as well as task dependencies. Using the clash detection functionality of Synchro Pro, the prime contractor could also automatically check for clashes in the design, while considering the temporal aspect. An additional benefit of using 4D BIM tools for testing the feasibility and constructability was a lower tender price. By testing the feasibility of the risk mitigation strategies and the major construction strategies, the prime contractor was ensured of the soundness of its tender, and was able to reduce its risk profile.

The result was a highly effective overall strategy for mitigating the risk of nuisance. The client evaluated the risk mitigation strategies proposed by this prime contractor and assigned the overall plan with an outstanding added value. Most effective strategies cited by the client were to keep the middle lock operational for four years out of five years of construction duration, and to minimize the use of canal locks and waterways for construction purposes.

4.1.2.2. Evaluation of the MEAT criterion 4D BIM & construction logistics

One of the three prime contractors expressed that its main reason for implementing 4D BIM was because the client demanded it. The two other prime contractors indicated that the effort they had made for the 4D BIM call would not have been much more if 4D BIM had not been requested by the client, only the focus of the effort would have been different. Due to the request of the client, the prime contractors also focused on minimizing nuisance to traffic when using the 4D model, instead of focusing alone on reducing construction duration and costs. Therefore, **demanding the application and submission of BIM was an effective incentive for motivating the prime contractors to apply BIM for minimizing nuisance to traffic**.

It should be noted that the most important incentive was the benefits of BIM perceived by the prime contractors. The three competing contractors were a consortium of multiple companies. In each consortium, a company that specializes in the BIM use was involved. The three competing prime contractors said that they see BIM as an essential tool for complex infrastructure projects, where multiple disciplines are involved. They also expressed that they would implement BIM even if the client did not demand it. For two of the three competing contractors, the investments related to BIM would also remain the same even if the client did not demand BIM implementation. Their investments related to BIM included one BIM modeler for each discipline and one or two full-time employees (fte's) for managing and coordinating the BIM-related activities throughout the procurement phase.

There are also points for improvement. First, **candidates should be given clear guidelines with which they can determine whether they have complied with the requirements or whether they have to make further efforts**. In this project, the requirements in the tender guidelines differ from the explanation that the candidates received during the dialogue and the guidelines were not updated to include the changes. An example of this is that other file formats (except IFC) are also allowed. It was unclear to the candidates how the 4D BIM plan is assessed and how this assessment is included in the overall assessment of their registration. It was therefore unclear to the candidates whether their registration could be invalidated due to the 4D BIM plan, which caused a lot of unrest among the candidates.

Another point of improvement relates to the content of the 4D model. The client could navigate in the 4D model and turn elements on and off. The client had to decide which elements to switch on and off and on which angle to view the model. It may therefore take some time to understand the 4D models supplied and to turn the right elements on and off and to use the correct approach to get the right information from the 4D model. In the future, prime contractors should save and include viewpoints in the submitted 4D models, which the client can use as starting points for navigating through the model.

Last, it is not recommended to request the 3D and 4D models as validity products. The models are set up, e.g. a design vision with a bandwidth of sometimes 20% - 30%. In a tender, this bandwidth can easily be 50%, especially on steel quantities. As a validity product, the model is therefore valid within a certain bandwidth. The bandwidth of the model must therefore be known, only it is difficult to determine the bandwidth of a model because it differs per element. In addition, there are no standards to determine this.

4.2 1ST REDESIGN OF THE TREATMENT

In this section, the points for improvement resulting from the TAR will be implemented in the PDEng design products. The PDEng design products evaluated in the TAR are BIM scenario #2 (4D modeling) and incentive #2 (MEAT criterion 4D BIM and construction logistics). The resulting redesign of BIM scenario #2 and incentive #2 will be presented in subsections 4.2.1 and 4.2.2, respectively.

4.2.1. Redesign of BIM scenario #2

Based on the evaluation of BIM scenario #2 by the client and the three competing prime contractors, BIM scenario #2 mostly satisfied the logistics requirements of the organizations. One logistics requirement of the client was not satisfied. To completely satisfy the requirements, one solution (Solution #12) is added to the BIM scenario #2 for its application during the tender phase.

Box 12. Solution #12.

Logistics requirement

- Determine how much construction related traffic is expected for each construction phase (volume and direction) and its effect on public and temporary roads.

Solution #12: BIM scenario 2 (4D modeling)

- Make a 3D model for each design discipline
- Make a 3D model of temporary facilities and cranes
- Integrate these 3D models and link with alternative execution schedules
- Generate quantity of materials to be transported per time unit for alternative execution schedules
- Develop alternative transportation options
- Calculate expected volume of construction related traffic per time unit and per road section for alternative transportation options
- Input calculated volume into traffic simulation models
- Compare lost vehicle hours per road section of alternative transportation options

Examples:

Evaluatiegegevens

Rich-ting	Int. [pae/u]	Cap. [pae/u]	Eff. groen [sec]	Verz. graad [%]	Gem. verl.tijd [sec]	Delay [pae.u/u]	Gem. stops [pae/sec]	Gem.max. wachtrij [pae]	Overf. queue [pae]	Opstel cap. [m]	Verw. overschr. [/u]	Benod. opst.cap. P=5[%] [m]	Benod. opst.cap. P=10[%] [m]
002	367	1460	22	86	39,4	4,0	0,11	8,0	1,7	100	0	84	78
005	44	1820	7	26	31,6	0,4	0,01	0,8	0,0	100	0	24	18
026	40	5000	7	9	31,1	0,3	0,01	-	0,0	100	-	-	-
028	40	5000	7	9	31,1	0,3	0,01	-	0,0	100	-	-	-
033	100	9999	9	8	29,3	0,8	0,02	-	0,0	8	-	-	-
035	100	9999	9	8	29,3	0,8	0,02	-	0,0	6	-	-	-
036	100	9999	12	6	26,7	0,7	0,02	-	0,0	9	-	-	-
042	38	1920	8	19	30,5	0,3	0,01	0,7	0,0	100	0	18	18
048	38	1640	8	22	30,6	0,3	0,01	0,7	0,0	100	0	18	18
061	82	1640	7	54	32,4	0,7	0,02	1,6	0,0	100	0	30	24
065	172	1720	9	83	55,1	2,6	0,06	4,6	1,3	100	0	54	48
068	707	1660	37	86	24,5	4,8	0,18	11,5	1,8	81	13	108	102

Cyclustijd 75 [sec]
Gem. verliestijd 32,1 [sec]
Doelfunctie 16,28

Calculating lost vehicle ours (*image from Ministerie van Verkeer en Waterstaat (2008)*)

4.2.2. Redesign of incentive #2

Based on the evaluation of the products during the Technical Action Research (TAR), it was found that the MEAT criterion 4D BIM and construction logistics should be adjusted. The adjustments to the incentive are discussed below.

General requirements on the 4D model

At the moment of the study, there were no open standards available for exchanging 4D models. When clients demand that prime contractors should deliver the 4D model in an open format, then there is a risk that information will be lost in the conversion of the native 4D file formats to IFC, for example.

Therefore, the client is advised not to limit the request to IFC. Recommendation is to leave the choice to the prime contractor, with the condition that the 4D model must be viewable by the client with a viewer that is freely accessible in the market. The prime contractor is also requested to submit a document explaining the contents of the 4D model (such as meanings of representations and color schemes) and instructions for installing the 4D model viewer.

Contents of the 4D model

Based on the evaluation by the three competing prime contractors, prescribing the level-of-detail and level-of-development of the 4D model limits the prime contractor's chance to decide how to setup and fill in the model. Therefore, the client must take care not to dictate the contents of the 4D model. The prime contractor should be given the freedom to determine how the 4D model should be setup and filled in. This includes the *level-of-detail* of the 4D model. Instead, the client is advised to specify functional requirements of the 4D model, by specifying *what* the 4D model should show.

Examples of functional requirements that the client could specify are:

- The 4D model should demonstrate the continuity of the primary functions of the infrastructure/facility throughout the construction process
- The 4D model should demonstrate the availability of the facility throughout the construction process, taking into account the effects of the proposed MEAT strategies
- The 4D model should visualize the extent of different types of nuisance (for example: the extent of noise nuisance and which roads/areas are affected) during the entire construction process in which the effects of the proposed MEAT strategies are taken into account.

For demonstrating his MEAT strategies and their effects, the prime contractor should define viewpoints in the 4D model. Viewpoints are snapshots of the model, which are taken in a specific perspective and can contain comments and tags. They support the review of the model by taking the reviewer to a predefined perspective from which to (begin to) view the model.

These changes will be incorporated in the design of incentive #2: MEAT criterion 4D BIM and construction logistics. The redesigned incentive will be validated through expert opinion, which will be discussed in the next section.

4.3 VALIDATION: EXPERT OPINION

The second step in treatment validation is to gather expert opinion. Two sessions were conducted to test 1) the (redesigned) BIM scenarios for construction logistics, and 2) the (redesigned) incentives for applying BIM scenarios for construction logistics and the addendum to the BIM protocol. The first session will be discussed in subsection 4.3.1, followed by the second session in subsection 4.3.2.

4.3.1. Expert opinion on the BIM scenarios for construction logistics

A workshop was conducted with a panel of experts to evaluate the BIM scenarios for construction logistics (*for the list of participants and the tables of the participants' responses, see Appendix K*). The participants were asked to evaluate whether a logistics requirement was important or not. The results are shown in Table **30**.

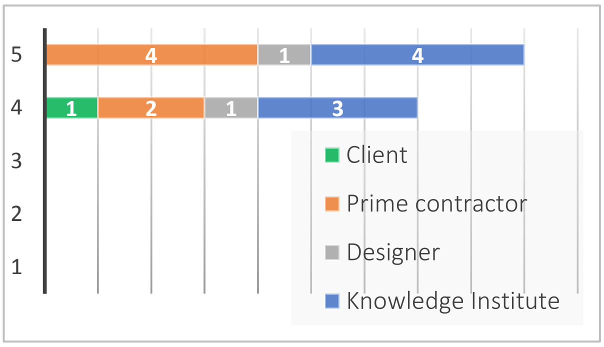
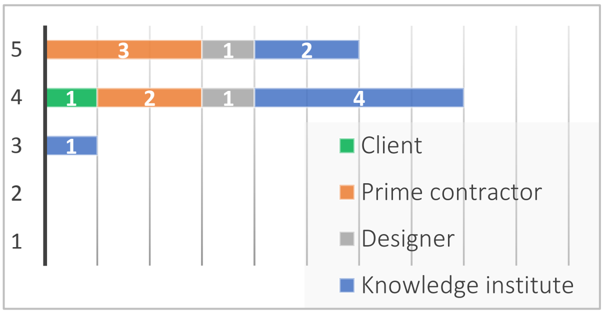
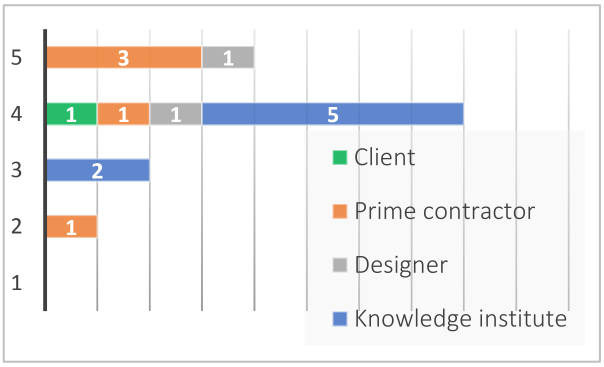
Table 30. Most important logistics requirements for each organization.

Organization	# of participants	Most important logistics requirements
Clients	1	• Consistently process design changes in all drawings • Clearly visualize and communicate the location, context and quantity of specific elements with certain specifications • Independently generate and use information out of the design
Prime contractors	6	• Efficiently analyze and compare effects of alternative construction phase planning on traffic flows and the availability of public and temporary roads • Clearly visualize and communicate the location, context and quantity of specific elements with certain specifications • Align production models from various disciplines with each other • Determine what, when and how much should be delivered, and eventually optimize delivery options
Designers	2	• Align designs from various disciplines • Optimize construction method and construction sequence, and eventually optimize design • Align production models from various disciplines with each other • Determine what, when and how much should be delivered, and eventually optimize delivery options
Subcontractors and suppliers	0	-
Knowledge institutes	7	• Align designs from various disciplines • Clearly visualize and communicate the location, context and quantity of specific elements with certain specifications • Determine what, when and how much should be delivered, and eventually optimize delivery options • Monitor if orders will be delivered on time, and view the consequences of delivery time on construction activities

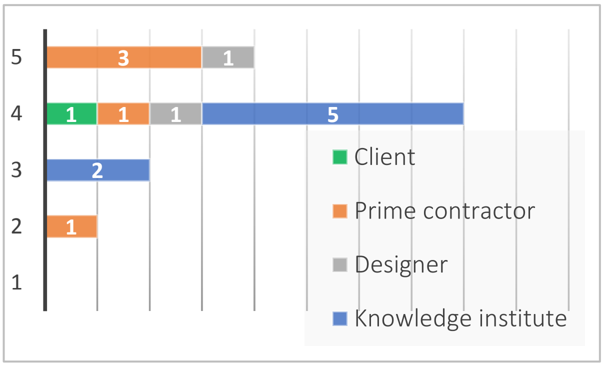
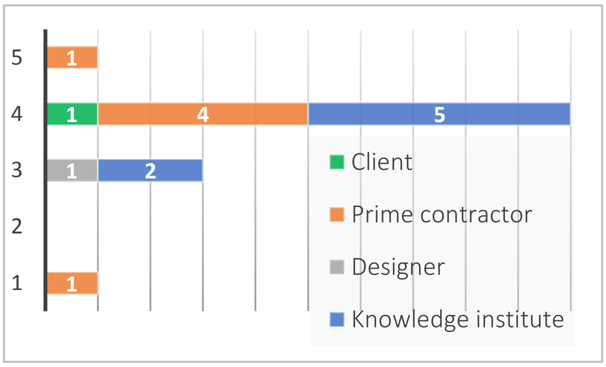
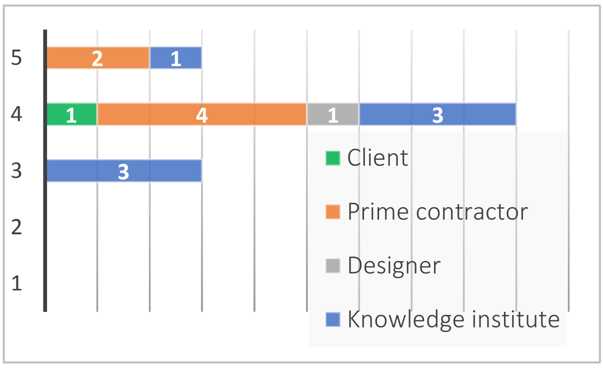
The participants responded that most of the logistics requirements are either "important" or "very important". One significant response from a prime contractor was that the logistics requirement: "Manage the stock on site" was "very unimportant". According to lean principles, such a requirement will become irrelevant due to just-in-time delivery. Therefore, more importance should be given to coordinating and monitoring if orders will be delivered on time.

The participants were also asked to specify important logistics requirements that were missing from the list. Additional logistics requirements given by the participants included safety analysis of logistics routes, bundling potential for suppliers, and the need to involve subcontractors and suppliers during the tender phase. Afterwards, the participants were asked to evaluate whether the proposed solutions using the BIM scenarios for construction logistics satisfied the above logistics requirements. Table **31** lists the results of the evaluation for each proposed solution.

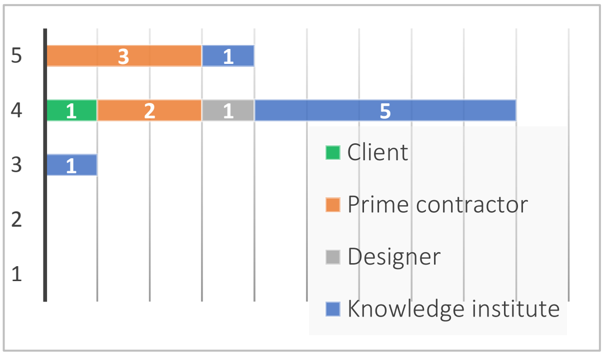
Table 31. Evaluation of BIM scenarios for construction logistics.

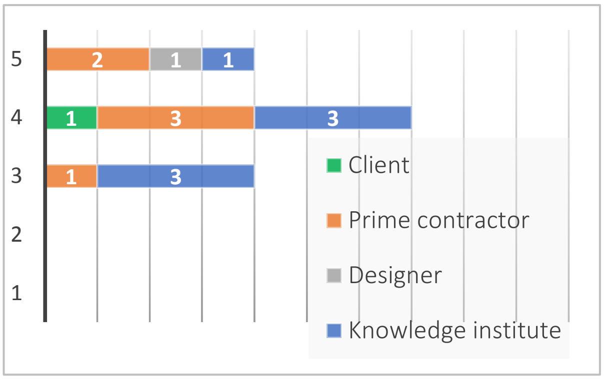
Solutions	Satisfies the requirement?
Requirement: Align designs from various disciplines, which results to less design errors and consequently, less disruptions to the execution and logistics process. Solution: BIM scenario 1 1) Make a 3D model for each design discipline 2) Integrate 3D models from design disciplines 3) Check the 3D models for interface clashes or other errors	
Requirement: Consistently process design changes in all drawings, which results to less errors in drawings and consequently, less disruptions to the execution and logistics process. Independently generate and use information out of the design. Solution: BIM scenario 1 1) 3D modeling/designing 2) Information is entered once, is consistent (uniform) and non-redundant 3) Generate 2D drawings from the 3D model 4) Use 3D model as basis for 3D production model	
Requirement: Align the design with the circumstances on site. Optimize construction method and construction sequence, and eventually optimize design. Solution: BIM scenario 2 1) Make a 3D model for each design discipline 2) Make a 3D model of temporary facilities and cranes 3) Integrate the 3D models and link with execution schedules 4) Generate quantities of materials required to be supplied for each time unit (day, week, etc.) 5) Visualize construction site design for each time unit, and eventually optimize design	

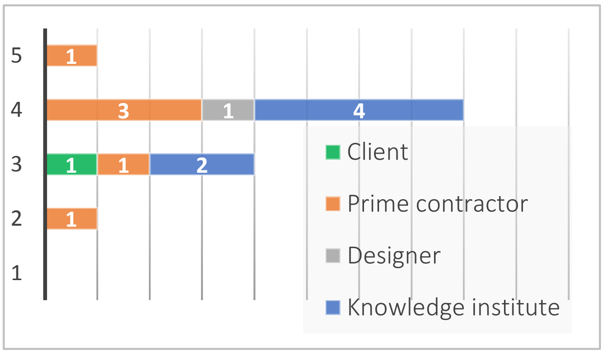
Continuation of Table 31. Evaluation of BIM scenarios for construction logistics.

Solutions	Satisfies the requirement?
Requirement: Efficiently analyze and compare effects of alternative construction phase planning on traffic flows and the availability of public and temporary roads. Solution: BIM scenario 2 1) Make a 3D model for each design discipline 2) Make a 3D model of temporary facilities and cranes 3) Integrate these 3D models 4) Link with execution schedules 5) Use 4D model to show where and when nuisance to public and temporary roads will take place 6) Link 3D/4D model with traffic simulation models 7) Link 3D/4D model with GIS	
Requirement: Clearly visualize and communicate the location, context and quantity of specific elements with certain specifications (what, where and how much). Independently generate and use information out of the design. Solution: BIM scenario 1 1) Receive integrated 3D design model 2) Generate 2D drawings from the 3D model 3) Use of filters and query on element type and parameter 4) Make a 3D production model	
Requirement: Align production models from various disciplines with each other, which results to less design errors and consequently, less disruptions to the construction and logistics process. Solution: BIM scenario 1 1) Make a 3D production model for each supplier 2) Integrate 3D design model and 3D production models 3) Check the 3D models for interface clashes or other errors	

Continuation of Table 31. Evaluation of BIM scenarios for construction logistics.

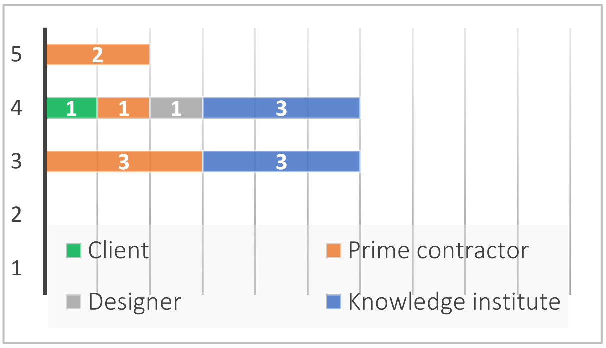
<table>
<tr><th>Solutions</th><th>Satisfies the requirement?</th></tr>
<tr><td>
Requirement:
Independently navigate through the design from each possible perspective and at various moments during the construction process to gain insight into the conditions for execution.
Solution:
BIM scenario 2
1) Navigate in 4D model
2) Use of viewpoints and tags
</td><td>


</td></tr>
<tr><td>
Requirement:
Determine what, when and how much should be delivered, and eventually optimize delivery options.
Solution:
BIM scenario 2
1) Receive integrated 3D design model
2) Link with a schedule (production schedule, delivery schedule or execution schedule)
3) Use 4D model to determine moment of preparation, production, delivery and execution of an object
4) Generate quantity of materials to be delivered for a specific day
5) View geometric properties and packaging properties of objects to be delivered for a specific day and optimize bundling of objects, to maximize truck load and minimize traffic movements
</td><td>


</td></tr>
<tr><td>
Requirement:
Monitor if orders will be delivered on time, and view the consequences of delivery time on construction activities.
Manage the stock on site.
Solution:
BIM scenario 2
1) Receive integrated 3D design model and link with a schedule
2) Use 4D model to monitor the status and moment of preparation, production, delivery and execution of an object
3) Link with wireless technology such as RFID-tags and barcodes
4) Use of equipment to scan RFID-tags and barcodes, so that location of objects can be viewed in the model
5) Use 3D/4D model to view the status of objects, such as ‘in production’ or ‘in storage’
</td><td>


</td></tr>
</table>

Continuation of Table 31. Evaluation of BIM scenarios for construction logistics.

Solutions	Satisfies the requirement?
Requirement: Align on a detailed level which party is working where and when. Optimize use of space on site. Solution: BIM scenario 2 1) Use 4D model to visualize permanent and temporary facilities on site, including a schedule of activities 2) Manage storage locations, access routes to the site, setup of temporary facilities and cranes	

As can be seen in **Table 31**, the experts evaluated that the solutions using the BIM scenarios for construction logistics satisfy the logistics requirements. Three comments were given regarding the application of BIM scenario #2: 4D modeling. First, although the experts agree that this BIM scenario is the best method to address the related logistics requirements, the application of this BIM scenario still takes a lot of effort in practice. Second, 4D modeling is often applied to *validate* design and planning solutions, and not really to *formulate* design and planning solutions. Last, with regards to monitoring the status of orders using the 4D model, a simpler solution would be to add a text attribute to 3D objects that are critical for the planning. This attribute would display the status as *ordered*, *in production*, *delivered*, or *installed*.

4.3.2. Expert opinion on products 2 and 3

Two contract managers were individually consulted to evaluate product 2 (incentives for applying BIM scenarios for construction logistics) and product 3 (addendum to the BIM protocol). The first expert is a contract manager on the side of the client, and has experience on working with prime contractors using BIM for construction logistics and on managing contracts with stipulations regarding BIM in large infrastructure projects. The second expert is a contract manager on the side of the prime contractor, has experience on formulating and managing contracts with stipulations regarding BIM, and has previously conducted research on how to embed BIM in various contract models in the Netherlands and the United States of America.

In each consultation, the PDEng trainee first briefly presented the two BIM scenarios for construction logistics, the two incentives for applying BIM scenarios for construction logistics, and the addendum to the BIM protocol. Next, the experts were asked to evaluate the incentives and addendum. They were asked to evaluate two aspects: 1) whether the products contained deficiencies or errors; and 2) whether they perceive that the products will be effective in motivating organizations to apply BIM scenarios for construction logistics in the intended way.

Both experts are generally satisfied with the products. According to both experts, the incentives positively influence the motivation of contracted organizations (prime contractor in the 1st layer relationship; designers, subcontractors and suppliers in the 2nd layer relationship) to apply BIM scenarios for construction logistics. Few points for improvement were suggested for both products. The resulting points for improvement will be discussed in the next section (section 4.4).

With regards to the addendum to the BIM protocol, both experts also positively evaluated the contents. The second expert expressed that the incentive “sharing of savings” is often stipulated in the contract itself. It is not necessary to stipulate this incentive in the BIM protocol. Therefore, by referring to the paragraph number relating to the incentive in the contract itself in section 4 of the addendum (*Gekoppelde afspraken*) is sufficient.

4.4 2ND REDESIGN OF THE TREATMENT

In this section, the points for improvement identified during the second round of validation will be implemented in the designs of the three products. First, the redesign of product 1 will be discussed in subsection 4.4.1, followed by the redesign of product 2 in subsection 4.4.2. Finally, the redesign of product 3 will be discussed in subsection 4.4.3.

4.4.1. Redesign of the BIM scenarios

Based on the opinion of the experts, the BIM scenarios for construction logistics mostly satisfy the requirements. This means that there are no changes to the BIM scenarios for construction logistics in this round.

4.4.2. Redesign of the incentives

Changes to incentive #1: Sharing of savings

The experts evaluated incentive #1 positively and suggested minor points for improvement to include an example of how this incentive should be anchored in the contract. Expert #2 explained that agreements regarding sharing of savings are usually stipulated in the contract itself. For agreements regarding the application of value engineering using BIM, Expert #2 suggested that the purchasing contract can include the following stipulation:

"If the contracted party sees opportunities to carry out the work more efficiently, less expensive and/or faster ('Value Engineering'), he will inform the contracting party of this by means of a change request. Either party will subsequently draft a change request regarding the potential Value Engineering, including the potential (time) savings, as well as a proposal for the distribution of these savings. A proposal for Value Engineering can only be conducted by the contracted party if the contracting party has given a written order for this. The contracting party has the right to reject a Value Engineering proposal without stating reasons, and without having to compensate anything to the contracted party."

Expert #2 also stressed the importance of the footnote in applying the incentive. Trust and transparency between the organizations are very important preconditions for applying this incentive in practice. Often, this can be achieved by long-term relationships between organizations.

Changes to incentive #2 MEAT criterion 4D BIM and construction logistics

The 4D model can be used similarly to an existing tool (DuboCalc), which supports Rijkswaterstaat's MEAT criterion on sustainability. This means that the quality of the 4D model itself won't be evaluated. Instead, the evaluation will focus on the proposed strategies and their effects that are demonstrated by the 4D model.

The evaluation of the bids for the MEAT criterion 4D BIM and construction logistics will then be conducted as follows:

1) The offer indicates which degree, category and duration of nuisance (referred to as nuisance mitigation strategy performance) is offered. The indication is given in the form of a number or category (see Taskforce Doorstroming (2009)) and should be supported by the 4D BIM. This means that the 4D BIM should demonstrate and coincide with the offered nuisance mitigation strategy performance.
2) A percentage is deducted from the bid price due to the nuisance mitigation strategy performance. We call this amount A.
3) The client determines which combination of degree, category and duration of nuisance scores a 6 and which a 10.
4) The MEAT score is determined on the basis of the promised performance. With this score, the MEAT amount is calculated using the MEAT calculation system. This amount (together with the amounts for the other MEAT criteria) is deducted from amount A and gives amount B (both fictitious amounts).
5) The lowest fictitious amount B of all offers wins the tender

The above changes will be incorporated in the design of the two incentives for applying BIM scenarios for construction logistics. The final design of incentive #1 and incentive #2 are presented in Appendix L and Appendix M, respectively.

4.4.3. Redesign of the addendum to the BIM protocol

The experts positively evaluated the addendum to the BIM protocol and suggested two points for improvement. First, section 4, which contains the link to the incentives, can also contain a table showing the payment schemes for risk mitigation strategies and the linked performance targets. This way, the organizations participating in fulfilling the risk mitigation strategies become more aware of the costs of the strategies and their link to the performance targets.

Second, the delivery of BIM data can also be linked to payment schemes of work packages. For example, for each work package, the delivering organization would receive the first payment item after delivery of the "as-designed" model. Then, after the work has been executed, the delivering organization would only receive complete payment of the work package after the completion and submission of both the physical work and the "as-built" model.

4.5 CONCLUSIONS ON THE TREATMENT VALIDATION

Based on the results of the investigation phase, conceptual designs of the three products were developed. In this chapter, the validation of these products were discussed. The conclusions of the validation phase for each product are given below.

Product 1: BIM scenarios for construction logistics – In the previous chapter, two BIM scenarios for construction logistics were designed. The BIM scenarios link BIM with construction logistics by reporting its benefits for construction logistics in a project with a traditional or an integrated contract type. In this chapter, the two BIM scenarios were tested, first through TAR in the New Lock Terneuzen project, and then through expert opinion.

In the TAR, the PDEng trainee applied BIM scenario #2 to the project by providing the client and the three competing prime contractors with a basis for how BIM should be applied in the project to optimize construction logistics. The prime contractors then further elaborated BIM scenario #2, which resulted to three variations of the BIM scenario. Two of the three prime contractors experienced benefits from the application of the BIM scenario. Moreover, the client experienced benefits from the application of the BIM scenario. Through the application of the BIM scenario, it was possible to maximize the availability of the canal locks facility, thereby minimizing the nuisance to shipping traffic and potential CO_2 emissions throughout the construction phase.

In the second round of validation, experts from various organizations evaluated that the solutions using the two BIM scenarios for construction logistics satisfy the logistics requirements. This resulted to no changes to the design of the BIM scenarios.

Product 2: Incentives for applying BIM scenarios for construction logistics – In the previous chapter, two additional incentives for applying BIM scenarios for construction logistics in a project were designed. They provide recommendations for contracting organizations (client or prime contractor) to motivate other organizations to use BIM in a project, with the aim of optimizing construction logistics. In this chapter, the two incentives were tested. Incentive #1 was tested through expert opinion. Incentive #2: MEAT criterion 4D BIM and construction logistics was first tested through TAR in the tender of New Lock Terneuzen, and then through expert opinion.

In the TAR, the PDEng trainee applied Incentive #2 to the project by providing the client with a basis for developing the 4D BIM requirements. The result was a variant of the MEAT criterion 4D BIM and construction logistics. After the awarding of the contract, the client and three competing prime contractors evaluated the 4D BIM requirements, which resulted to a redesign of the MEAT criterion 4D BIM and construction logistics.

In the second round of validation, two experts evaluated Incentive #1 and Incentive #2. Both experts evaluated both the incentives positively, and minor points for improvements were suggested, which resulted to a redesign of the two incentives (shown in Appendix L and Appendix M).

Product 3: Addendum to the BIM protocol – In the previous chapter, the addendum to the BIM protocol was designed. The addendum contains agreements regarding the delivery of information needed for the BIM scenarios for construction logistics and the incentives linked to the BIM scenarios. In this chapter, the addendum was tested through expert opinion. Two experts were asked to evaluate the addendum. Both experts evaluated the addendum positively, and no changes were made to the addendum.

Chapter 5. Conclusions, discussions and recommendations

The three design phases that were followed to produce the three products were discussed in the previous chapters. In this chapter, the conclusions of the PDEng design project, and discussions and recommendations arising from the PDEng project will be presented. This chapter is structured as follows. First, the results of this PDEng project will be summarized in section 5.1. Second, the main limitations of this project will be discussed in section 5.2. Third, recommendations for the construction sector in the Netherlands and for future studies will be given in section 5.3.

"You look at where you're going and where you are and it never makes sense, but then you look back at where you've been and a pattern seems to emerge."

-Robert M. Pirsig, Zen and the Art of Motorcycle Maintenance

5.1 CONCLUSIONS

An important reason to start this PDEng project was to motivate organizations to optimize construction logistics using BIM. The transport of construction goods is a significant contributor of pollution to our environment. Optimization of construction logistics will significantly reduce CO_2 emissions and nuisance to traffic caused by construction related activities. The use of BIM supports construction logistics optimization, and therefore, it is important that organizations are stimulated to use BIM for construction logistics optimization.

In line with this, the main objective of this PDEng design project was to incentivize the use of BIM for construction logistics optimization, by: 1) making the potential benefits of BIM for construction logistics known, 2) creating incentivizes for applying BIM uses for construction logistics, and 3) aligning contractual arrangements with (incentives for) BIM uses for construction logistics. The achievement of these objectives was accomplished by following the design cycle, which is illustrated in Figure 16.

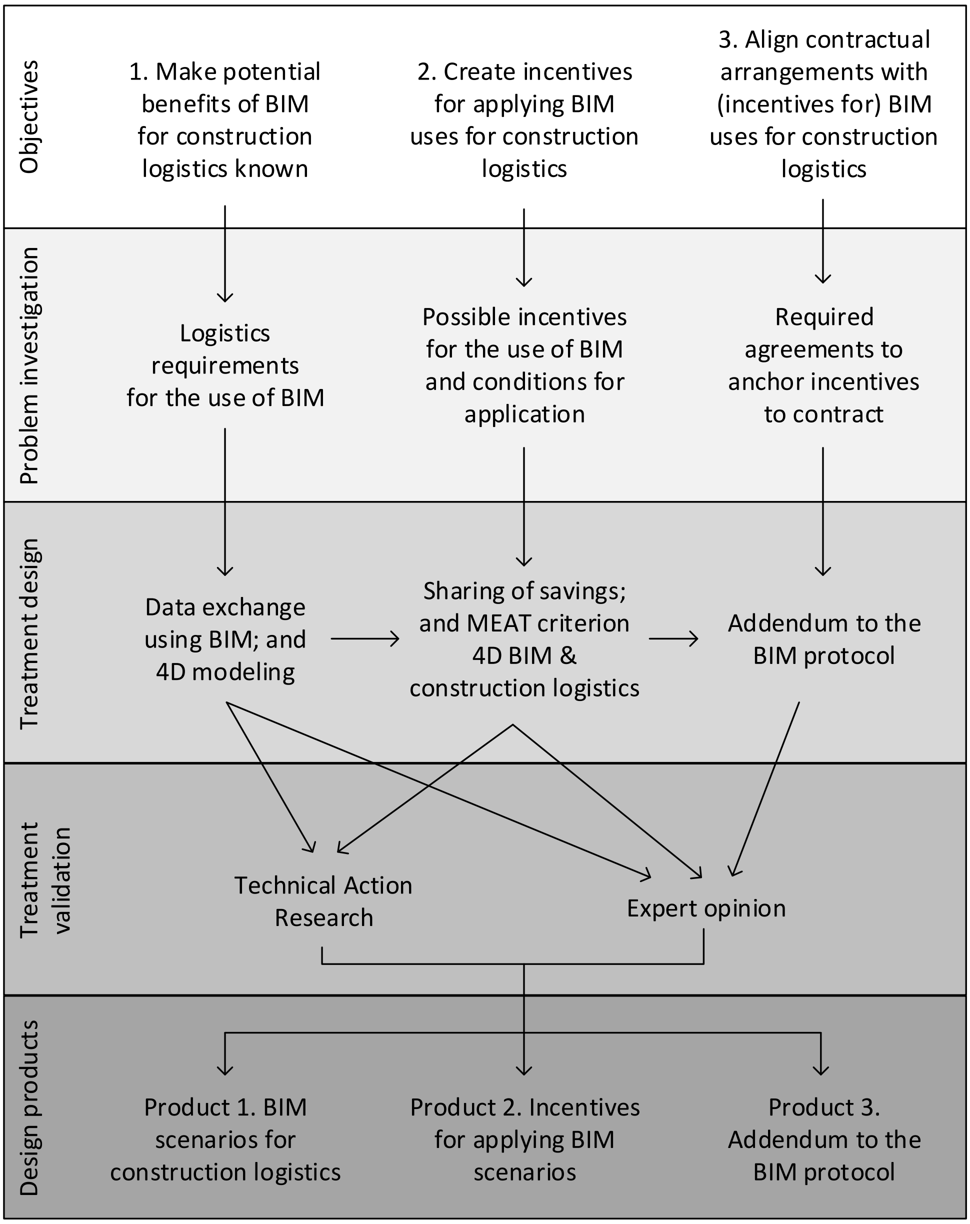


Figure 16. Summary of steps to design the three PDEng products.

As a result, three products were developed: ① BIM scenarios for construction logistics, ② incentives for applying BIM scenarios for construction logistics, and ③ addendum to the BIM protocol. How each of these products contribute to the reduction of nuisance and CO_2 emissions will be described below.

Product 1. BIM scenarios for construction logistics

BIM scenarios for construction logistics describe how BIM could be used to support construction logistics optimization within a specific collaboration setting, and their potential benefits for the participating organizations. Each BIM scenario is composed of multiple BIM uses that describe a certain way of applying BIM to support construction logistics optimization.

Two BIM scenarios for construction logistics were designed. BIM scenario #1 is *Data exchange using BIM*, in which the model is used for storing and exchanging data (Figure **17**). The model serves as a repository of data that can be retrieved by multiple applications used by project partners and/or project disciplines working in the same project. Information is entered once, is consistent (uniform) and non-redundant.

Through this BIM scenario, errors in the design (drawings) and the lack of correct information are addressed, which results into less disturbances in the execution and logistics processes. Furthermore, construction partners can generate information regarding what, in which context and how much materials should be delivered to the construction site. As such, this scenario is a precondition for achieving optimal construction logistics.

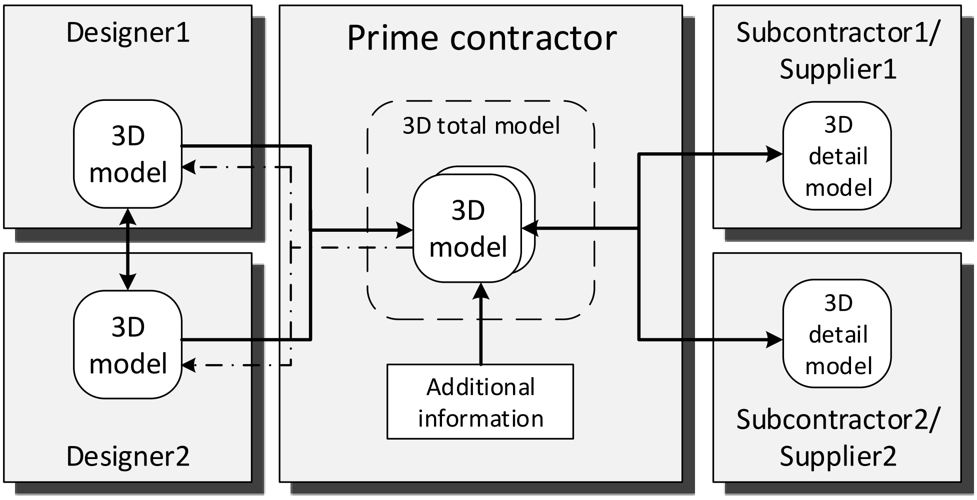


Figure 17. Data exchange using BIM.

BIM scenario #2 is *4D modeling*, in which the 3D geometries and location of objects in the model are linked to temporal information, such as the timings of their production, delivery or construction. An advantage of model-based scheduling is that it captures the spatial components related to activities, and directly links activities with the design. Through this link, the schedule can remain in sync with the design, and stakeholders are able to easily understand the schedule, evaluate its feasibility and its impact on logistics.

Through this BIM scenario, construction partners can generate information regarding *when* and in which time slots deliveries should take place. When BIM is linked with GIS (Figure **18**), construction partners can also generate information regarding *where* in the construction site should the materials be delivered, and which delivery routes and access points to take for an optimal transportation and handling of materials.

The two BIM scenarios were then validated through Technical Action Research and expert opinion. In the TAR, the PDEng trainee applied BIM scenario #2 to the project by providing the client and the three competing prime contractors with a basis for how BIM should be applied in the project to optimize construction logistics. Two of the three prime contractors experienced benefits from the application of the

BIM scenario. Moreover, the client experienced benefits from the application of the BIM scenario. Through the application of the BIM scenario, it was possible to maximize the functional availability of the canal locks facility to four out of five years of the construction duration, thereby significantly minimizing the nuisance to shipping traffic and potential CO_2 emissions throughout the construction phase.

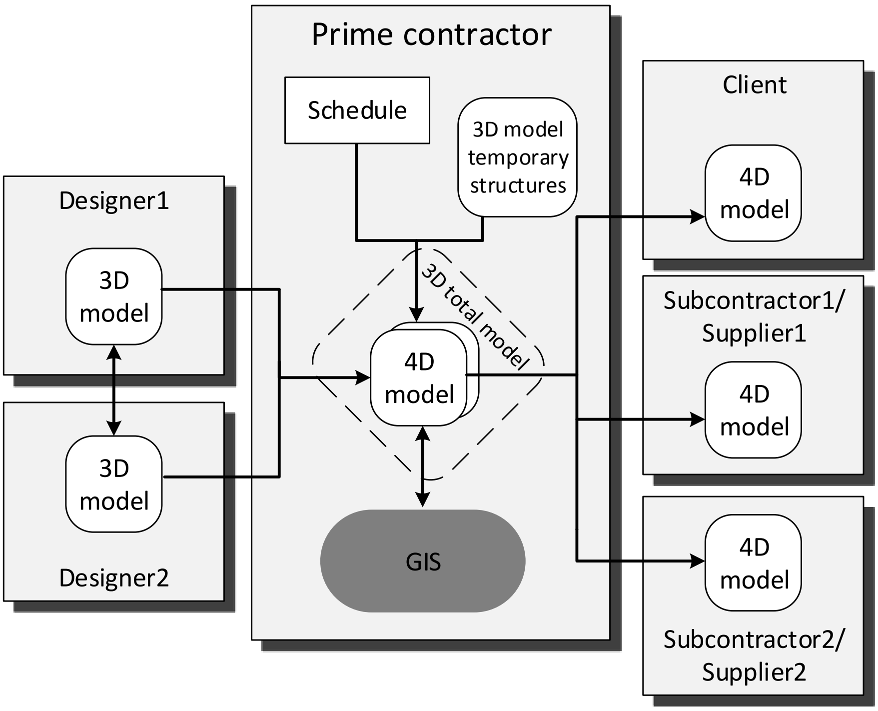


Figure 18. 4D modeling with link to GIS.

In the second round of validation, experts from various organizations evaluated that the solutions using the two BIM scenarios for construction logistics satisfy the logistics requirements. This resulted to no changes to the design of the BIM scenarios.

Product 2. Incentives for applying BIM scenarios for construction logistics

The incentives for applying BIM scenarios for construction logistics aim to motivate an organization to the intended use of BIM. The incentives contain guidelines for formulating and applying rewards and penalties for the intended use of BIM for construction logistics. They can be applied in an integrated collaboration setting.

Two incentives for applying BIM scenarios for construction logistics in a project were designed. Incentive #1 is *Sharing of savings*. The prime contractor could pay the designer for the BIM activities related to applying measures or strategies to optimize design and logistics (such as adjusting the BIM model, and/or adding information to the model). In addition, actual savings realized by the prime contractor during the execution phase resulting from these measures or strategies will be shared with the designer (according to a predetermined percentage of distribution). This would motivate the designer to ensure that the BIM model is created in a manner that it could be used to realize the savings (during the execution phase).

Incentive #2 is the *MEAT criterion 4D BIM and construction logistics*. The goal of linking 4D models to the MEAT criterion Construction logistics is to steer the prime contractor to optimize construction logistics and minimize nuisance to the public during the execution phase. The linking of 4D models contributes to this goal by: forcing the prime contractor to thoroughly think about and work out his MEAT strategies using 4D modeling; supporting the prime contractor in proving and demonstrating the effectiveness of MEAT strategies; and supporting the client's tender and evaluation committee in understanding the (effects of) proposed MEAT strategies and consequently be more able to steer the prime contractor to the desired effects. This creates the incentive for the prime contractor to optimize construction logistics and reduce CO_2 emissions, for a better chance of being awarded the contract.

The two incentives were then validated. Incentive #1 was tested through expert opinion, while Incentive #2 - *MEAT criterion 4D BIM and construction logistics* was first tested through TAR in the tender of New Lock Terneuzen, and then through expert opinion. In the TAR, the PDEng trainee applied Incentive #2 to the project by providing the client with a basis for developing the 4D BIM requirements. The application of this incentive stimulated the prime contractors to optimize construction logistics and reduce nuisance to traffic, which led to the development of more effective risk mitigation strategies.

Product 3. Addendum to the BIM protocol

The addendum contains the recommendations for aligning the existing BIM protocols with (incentives for) the use of BIM for construction logistics. For the design of the addendum, the PDEng used the Nationaal Model BIM Protocol (BIR Werkgroup BIM Protocol, 2016a) and Nationaal Model BIM Uitvoeringsplan (BIR Werkgroup BIM Protocol, 2016b) as templates.

The resulting addendum contains agreements regarding the delivery of information needed for the BIM uses for construction logistics and the incentives linked to the use of BIM. The delivery of information was designed in accordance with the Information Delivery Scheme for 4D BIM (ILS 4D BIM) (see Figure **19**), for which a conceptual design was also developed by the PDEng trainee (see Appendix N). The addendum was then tested through expert opinion. Experts were asked to evaluate the addendum. They evaluated the addendum positively, and no changes were made to the addendum.

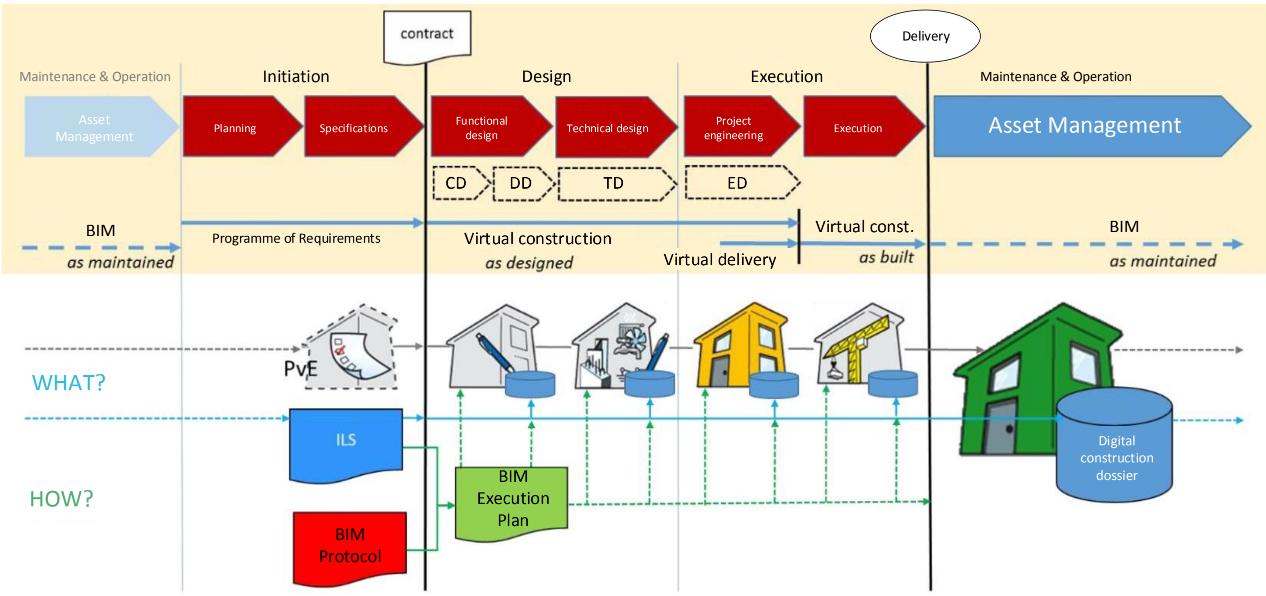


Figure 19. Relation between ILS, BIM Protocol, and BIM Exeuction Plan (BIR Werkgroup BIM Protocol, 2016a).

In conclusion, the three products contribute significantly to the reduction of nuisance and CO_2 emissions by stimulating and guiding the use of BIM for construction logistics optimization. This is evidenced by the experience from the case studies and supported by the opinion of practitioners, who were interviewed and participated in the workshops. As such, clients and construction partners are recommended to apply and further develop these products in practice. In section 5.3, the PDEng trainee discusses recommendations for the construction sector and for future studies.

5.2 Discussion

In the previous section, the main contributions of the PDEng project were discussed. In this section, notable points for discussion and the main limitations of the PDEng project will be highlighted.

First, integrated contracts are an important condition for optimizing construction logistics. They provide the opportunity and incentive to optimize construction logistics by integrating design and execution. When design and execution are not integrated, it limits the possibility for the prime contractor to optimize construction logistics, as well as the possibility to align ICT with his project partners.

In addition, an integrated contract between the client and the prime contractor is also a precondition for attaining a high level of integration between prime contractors, designers, subcontractors and suppliers. If design and execution are not integrated, then it limits the integration of designers, subcontractors and suppliers in product development and design.

Second, incentives can be effective for motivating organizations to apply BIM for construction logistics. However, a precondition for applying incentives is that organizations must have the capability to implement the BIM scenarios. Similarly, organizations that request the use of BIM scenarios must have knowledge and skills for working with BIM. Knowledge and skills regarding BIM is crucial for formulating BIM requirements and effective incentives.

Once the BIM requirements and incentives have been properly formulated, another important requirement for organizations requesting the use of BIM in the tender phase is the ability to evaluate the submitted (4D) BIM models. When the BIM requirements are not attached to evaluation criteria (for awarding of the contract), then organizations supplying the (4D) BIM models are less likely to understand what is needed to be modelled, and they may be less likely to invest effort into fulfilling the BIM requirements. Therefore, linking the BIM requirements with evaluation criteria – for example, through the MEAT criterion for minimizing nuisance or for optimizing construction logistics – is an important precondition for requesting (4D) BIM in the tender phase.

Moreover, the weight (percentage) of the MEAT criteria related to BIM and logistics should be large enough to motivate candidates (organizations supplying the (4D) BIM models) to address the MEAT criteria. In other words, these candidates weigh the costs of the strategies or measures against the amount of points that can be won for these strategies or measures. If the MEAT criterion has a large percentage (heavy weight), then candidates are more likely to develop strategies or measures that address these criteria.

One major limitation of this project was the lack of quantitative data on the effectiveness of 4D BIM on reducing nuisance. Future research should therefore measure the actual savings and reduction of nuisance and CO_2 emissions resulting from the use of 4D modeling. The results from such research should then be incorporated into action research, to facilitate learning and the uptake of 4D BIM in the construction sector. More recommendations regarding future studies will be given in the next section.

5.3 RECOMMENDATIONS

In this section, recommendations for the construction sector and for future studies are given. Subsection 5.3.1 lists recommendations for construction organizations to further optimize construction logistics. Subsection 5.3.2 provides recommendations for the next steps in future studies.

5.3.1. Recommendations for the construction sector

To further stimulate the use of BIM for CO_2 reduction and construction logistics optimization in the construction sector, the PDEng trainee highlights three recommendations for clients and construction partners. First, unexpected and adverse effects of risk mitigation strategies could stem from the way MEAT criterion is formulated. Therefore, clients should thoroughly think about how they formulate MEAT criteria. To support the client in this process, 4D modeling should be used to analyze the effects of MEAT criteria on the availability of the affected facilities and on the public and temporary roads.

Second, the case study showed that requesting 4D BIM during the tender phase led to considerable savings, less potential CO_2 emissions and less potential nuisance to the public. This means that further development of 4D BIM and its application in projects are necessary. The following steps are outlined for this:

- Collaboration between industry companies and the University of Twente should be continued to follow-up research focusing on and improving the ILS 4D BIM. Follow-up research is necessary to develop the recommendations of this study before it becomes a standard for the construction sector.
- Since the use of 4D BIM for construction logistics optimization is still scarce in practice, it is necessary to continue research and obtain insights into how to request and apply 4D BIM in an infrastructure project in an optimal way. The knowledge from this PDEng project must be transferred to environment managers, contract managers and project managers to obtain potential projects for the follow-up research. The managers should identify at least three infrastructure projects, and in these potential projects, the clients should request the use of 4D BIM in the tender phase.
- Most importantly, lessons learned from these projects should be centralized to facilitate learning and uptake of 4D BIM in the construction sector.
- The scope of Rijkswaterstaat (RWS) BIM program could be extended with 4D BIM aspects. By incorporating 4D BIM aspects, RWS can ensure that the recommendations of this study and the ILS 4D BIM can be elevated to market standard.
- Awareness of the chances of 4D BIM in relation to CO_2 reduction and the prevention of nuisance during construction must be stimulated among clients, project managers and at the project level.

Third, successful implementation of the PDEng products requires more cooperation in contract preparation between environment management, contract management, and information provision. In assessing the bids and awarding the contract, more emphasis should be placed on the importance of smart building logistics, reduction of nuisance and reduction of CO_2 emissions. The coordination of these goals in the chain can be achieved through a competitive dialogue.

5.3.2. Recommendations for future studies

The PDEng trainee outlines four main recommendations for future studies. First, a study should be conducted to understand how the use of BIM tools during the procurement phase of complex infrastructure projects could lead to the development and evaluation of more sustainable and effective risk mitigation strategies. The use of BIM tools during the procurement phase of complex infrastructure projects is a rarely researched phenomenon. Furthermore, little empirical evidence is available on the relation among the use of BIM tools during the procurement phase, the effectiveness of risk mitigation strategies, and the impact on sustainability. In-depth qualitative research is therefore necessary. In addition, this study could examine the value of BIM tools in other contract types and procurement methods, such as the traditional Design-Bid-Build or in an Integrated Project Delivery setting.

Second, there are no standard criteria for evaluating the effectiveness of risk mitigation strategies in relation to construction logistics. Therefore, future PDEng design projects can focus on developing standard evaluation criteria for MEAT related to construction logistics.

Third, future research could examine the planned application of BIM scenarios for construction logistics and the actual construction logistics optimization. A longitudinal case-study could be conducted to understand how the application of BIM scenarios for construction logistics throughout the project life-cycle could support the optimization of construction logistics and to monitor the implementation. During implementation, the savings should be measured quantitatively.

Fourth, a doctoral research can be conducted to study the implementation of 4D BIM in multiple projects through action research. In this action research, the doctoral candidate should be involved in the tender phase of construction projects to request and apply 4D BIM for construction logistics optimization. The aim of this research is to perform multiple design cycles in which recommendations for the application of 4D BIM will be further developed after every design cycle.

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APPENDICES

Appendix A. Construction logistics (information) needs

In subsection 2.1.1, the literature review conducted on BIM uses for construction logistics was described. A part of this literature review was to identify the construction logistics tasks of each organization, their (information) needs, the characteristics of the tasks, and bottlenecks.

The basic logistics tasks in each construction project phase obtained from literature can be subdivided into tasks performed by the client, designers, prime contractor, subcontractors and suppliers. The phase in which the tasks can be performed can vary depending on the project characteristics and the contract model. Tasks can be performed by different organizations, depending on the division of responsibilities. For example, environment management can either be performed by the client or by the prime contractor. The list is not comprehensive. Organizations can perform more logistics tasks than the ones listed below and there can be more (information) needs and bottlenecks than the ones reported.

A.1.1. Initiation/Programming phase

Client

At the initial phase of the construction project, logistics tasks of the initiator include investigating the local area of the project and identifying local and logistics constraints. These can include an investigation into the attitude of the neighbors towards the project and into the traffic levels in the surrounding area. After identifying the constraints, the initiator can prepare a list of requirements related to logistics and environmental guidelines, with which the contracted organization(s) must comply (Jupp, 2017).

Logistics tasks

- Checking the project concept from the logistics perspective
- Preparation of logistics (environmental) guidelines for tendering

(Information) Needs

Brief performance requirements, performance benchmarks, and site constraints: geo-spatial, available site information (British Standards Institution, 2013)

A.1.2. Design phase

Client

During the design phase, the client's logistics tasks can include checking the (changes in the) design for compliance with the logistics requirements and assisting with acquiring of permits (Jupp, 2017).

Logistics tasks

Evaluation of design against the logistics requirements

(Information) Needs

For road infrastructure projects, "[project] teams have to consider different public functions of areas surrounding the highway when establishing the impacts" (Zanen et al., 2013, p. 136). " [In-depth] understanding of public activities around a specific project and how these activities could be affected" is required (Zanen et al., 2013, p. 136).

Designers/architects/engineers

The designer's logistics tasks can include: considering logistics issues during development of the design and preparation of material requirement specification (Papaprokopiou, 2010; Sobotka, Czarnigowska, & Stefaniak, 2005). Designers can consider alternative structural designs and materials utilization to avoid difficulties presented by (large pieces of) materials. Consideration of logistics issues during design development creates the possibility of using prefabricated elements and improve the efficiency of construction logistics (Vrijhoef & Koskela, 2000).

Logistics tasks

Preparation of:

- Material requirement specification and logistics guidelines for the design
- Analysis of alternative structural designs and materials utilization

(Information) Needs

- Industrialization, such as the use of prefabrication, requires more substantial design and higher dimensional accuracy, and lengthens the correction cycle (Vrijhoef & Koskela, 2000)
- The use of prefabrication also requires input from the subcontractors/suppliers, and to align these inputs (Trebbe et al., 2015)

Bottlenecks

Long search for requisite information, incorrect documents, extended wait for approval of design changes (Vrijhoef & Koskela, 2000).

Prime contractor

The prime contractor's logistics tasks can include the preparation of the production design, which contains the "definitions of disposition and sequence of on-site activities and work teams, the use of equipments [sic.], and the arrangement and evolution of on-site work" (Serra & Oliveira, 2003, p. 79).

The prime contractor can also be tasked to prepare the construction site design, which defines the "size, shape and location of both permanent and temporary work areas and the circulation routes", including the areas for storage of materials and for living of the workers (Serra & Oliveira, 2003, p. 79).

Logistics tasks

Preparation of:
- Production design
- Construction site design
- Assessment of logistics service efficiency and impact on environment

(These tasks of the prime contractor can be performed in this phase in the case of integrated contract models, otherwise these tasks shift to the preparation phase.)

(Information) Needs

- Client requirements (British Standards Institution, 2013)
- Involvement during the design phase to simultaneously plan on-site production activities with the design development, to allow prime contractor to "influence, direct or indirectly, the production phase" (Serra & Oliveira, 2003, p. 77)
- Area and location of available space on site over the project duration for dynamic layout decision making of material storage and temporary facilities on-site (Said & El-Rayes, 2010)

Bottlenecks

- Separation between design and execution, and the lack of systems perspective/ integral approach can prevent logistics issues from being considered during the design phase (Rogers, 2005)

A.1.3. Preparation phase

Prime contractor

The prime contractor's logistics tasks can include procurement activities and setting up the logistics strategy/plan. In preparing the logistics plan, considerations include capacity analysis, productivity levels, number and location of unloading points, cranes and hoists, and constraints and possible risks that may occur during construction. Material procurement and storage planning are greatly dependent on: "the criticality of the construction activities consuming the material and the site space available" (Lodewijks, 2011, p. 9).

Logistics tasks

- Preparation of schedules and charts of labor and equipment utilization, subcontractors work and material consumption
- Selection of subcontractors and suppliers
- Planning of site activities
- Material procurement planning
- Material storage planning
- Waste management planning
- Planning information flows management and methods

(Information) Needs

- Material needs of each task/ link between materials and tasks (Ala-Risku & Kärkkäinen, 2006) over the project duration
- Spatial and temporal requirements of scheduled tasks (Said & El-Rayes, 2010)
- Bill of Materials and the geometry, location and context of materials (Zuiker, 2012)
- Materials and associated subcontractor and supplier prices and production lead times (Zuiker, 2012)
- "In-depth cost and time analyses" of logistics strategies are important for evaluating the trade-off between transportation, inventory and production costs (Vrijhoef & Koskela, 2000, p. 172). To effectively evaluate these trade-offs, cost transparency is required (Rogers, 2005).
- Effective communication and scheduling with suppliers to guarantee material availability without the build-up of unnecessary inventory (Ala-Risku & Kärkkäinen, 2006)
- Actual crane (or other lifting system) zones and movement sequences (British Standards Institution, 2013)

Bottlenecks

- Inaccurate data, adversarial bargaining (often leading to higher costs on site) (Vrijhoef & Koskela, 2000)
- "[Deficient] planning and information on the amount of requisite material", such as "missing information due to incomplete design data" (Vrijhoef & Koskela, 2000, p. 175)

Subcontractors/suppliers

Together with the prime contractor, subcontractors and suppliers prepare the supply plan and schedule, which indicate the proposed order and delivery dates of units for the whole project (Vrijhoef & Koskela, 2000; Zuiker, 2012).

Logistics tasks

- Preparation of Bill of Materials
- Preparation of supply plan and schedule
- Engineering design, which includes assembly level analysis and design, and piece level design and detailing

(Information) Needs

- Detailed drawings with demarcations, requirements specification, schedule, quantity take-off, building phases and building concept sketches, packaging requirements, general site conditions (Zuiker, 2012)
- Effective communication and scheduling with prime contractor (Ala-Risku & Kärkkäinen, 2006)
- Shorter (engineering) lead-times (for example, piece-detailing and generating quantity take-off) to increase flexibility, and decrease buffers and response time to design changes (Sacks et al., 2003)
- Need to level plant production across numerous projects (Sacks et al., 2003)
- Unique and constant identification of structural pieces (unique assembly control numbers) for preparing production and erection sequences (Sacks et al., 2003)
- Approval of engineering designs submitted for review by subcontractors/suppliers to designers/architects/ engineers

Bottlenecks

- Incomplete order specifications, lack of fixed practices, rushed orders (Vrijhoef & Koskela, 2000)
- Incomplete, erroneous definition of materials (Navon & Berkovich, 2006)
- For pre-cast concrete and prefabricated elements: long lead times due to intensive engineering design process and costly design errors (Sacks et al., 2003).

A.1.4. Construction phase

Prime contractor

In the execution phase, the prime contractor's logistics tasks include implementation of the logistics plan, and controlling and monitoring of the logistics process. The prime contractor can also be tasked for documentation, implementation and maintenance of the information system (Serra & Oliveira, 2003; Sobotka et al., 2005).

Logistics tasks

- Work progress monitoring
- Updating schedules and plans
- Adjusting orders to current demand for resources
- Planning and coordinating horizontal and vertical transport on site
- Planning and coordinating deliveries, loading and unloading deliveries
- Managing waste
- Managing information flows, documentation, implementation and maintenance of information system

(Information) Needs

- Schedule of tasks
- Short-term schedules for project tasks requires "transparency of material availability for site inventories and other stages of the supply chain" and "short response times along the supply chain" (Ala-Risku & Kärkkäinen, 2006, p. 1). More specifically, the planner needs "access to comprehensive information on materials availability for individual project tasks (Ala-Risku & Kärkkäinen, 2006, pp. 2-3).
- Daily activities managed by a more flexible approach based on an up-to-date schedule (Ala-Risku & Kärkkäinen, 2006)
- Effective means for creating visibility to (site) inventories, which includes reliable information on material availability and location on site or elsewhere along the supply chain (Ala-Risku & Kärkkäinen, 2006)

Bottlenecks

- No early consideration of site space and storage needs (Said & El-Rayes, 2010)
- Waste caused by damage to, loss and over-ordering of materials, design changes during construction phase, improper storing space and methods (Osmani, Glass, & Price, 2006).
- Materials arriving to the site at the wrong time (late or early arrival) either causing delay to a specific activity or requiring additional storage space, double handling and double equipment (Navon & Berkovich, 2006)
- Unsuitable materials that do not match the purchase order, wrong quantity of materials arriving to the site (Navon & Berkovich, 2006).
- Extra costs due to chaotic material deliveries, high variations in delivery times, unsystematic site organization, complex ordering procedures, procurement of large and difficult to handle materials (Vrijhoef & Koskela, 2000).
- Maintaining an up-to-date schedule is problematic, which leads to out-of-date schedule, which in turn leads to tasks unable to be performed "as they lack either predecessor tasks or other inputs" (Ala-Risku & Kärkkäinen, 2006, p. 2). In addition, materials are not registered in inventory control systems or there are errors in the registry due to manual processes and inconsistency, which leads to lack of information on material availability and condition (Ala-Risku & Kärkkäinen, 2006). Material shortages lead to low productivity and delay in execution of activities (Ala-Risku & Kärkkäinen, 2006; Navon & Berkovich, 2006).

Subcontractors/suppliers

Logistics tasks of subcontractors and suppliers can be categorized into the main categories of production, warehousing, transportation and assembly (Voordijk, 2000; Vrijhoef & Koskela, 2000).

Logistics tasks

- Production
- Warehousing /storage
- Transportation
- Assembly

(Information) Needs

- Accurate prime contractor demand information and visibility to upcoming material needs (Ala-Risku & Kärkkäinen, 2006).
- Subcontractors and suppliers "need to stay informed on the progress of the project", therefore, tools for communicating site inventory levels and updated project schedules are needed (Ala-Risku & Kärkkäinen, 2006, p. 4).
- Need to level plant production across numerous projects (Sacks et al., 2003)

Bottlenecks

- Delivery inaccuracies caused by delay in payment by prime contractor, change of sequence of works in construction site, errors in the design, errors in orders and difficulty in obtaining non-typical materials (Sobotka et al., 2005). Traditional construction logistics focuses on activities occurring on site and on short-term activities, which reinforces waste and problems (Vrijhoef & Koskela, 2000). Material inventories and time buffers are used to address uncertainty in the supply chain and varying site conditions. When materials are ordered late, high material buffers are made to guarantee service level. When materials are ordered too early, there is buffering at the site (Vrijhoef & Koskela, 2000).
- Long storage period (with associated costs for storage and maintenance), awkward packing, large shipments, problems with synchronizing the arrival of all components, synchronizing with site schedule, complex delivery procedures, order changes and lack of trust (Vrijhoef & Koskela, 2000).
- In some cases, large inventory buffers are requested by prime contractors, which reflects lack of trust on suppliers to supply on time (Sacks et al., 2003). Prime contractors then also bear the approximately 90% of the cost of the buffers (Sacks et al., 2003).

Appendix B. List of BIM uses

Table 32. List of BIM uses from literature.

List of BIM uses	
1	Generate 2D (production) drawings based on the 3D model
2	Generate documents based on BIM data
3	Visualize design using the 3D model
4	Data exchange with other project partners/ project disciplines
5	Lean engineering
6	3D modeling
7	Clash detection/ interface management
8	Designing with various project disciplines in one model
9	Design review
10	'Rule-based' design check
11	Integration of standardized model parts
12	Sustainability evaluation
13	Modeling of existing conditions
14	Analysis of installations (light, energy, thermal installations, and air ventilation)
15	Structural analysis in the model
16	Simulations and scenario analyses
17	Constructability analysis using the model
18	Simulation of the processes in the operation phase
19	Generate quantities from the 3D model
20	Coupling of the 3D model with a planning (4D modeling)
21	Purchasing management (demarcations)
22	Coupling of the 3D model with quality requirements
23	Cost estimation using the 3D model (5D modeling)
24	Labelling and numbering of objects for production, installation and logistics
25	Positioning via laser and machine guidance techniques
26	Quality Assurance/ Quality Control
27	3D coordination (management of subcontractors and suppliers)
28	Support of lean sessions with the model
29	Monitoring of logistics using RFID-tags and/or barcodes
30	Coupling of BIM with GIS (Geographic Information System)
31	3D modeling of temporary structures
32	Managing production process (Computer-Aided Manufacturing, CAM)

Appendix C. BIM uses for construction logistics

These 13 BIM uses for construction logistics were identified from literature (as discussed in subsection 2.1.1) and through the interviews with BIM managers and BIM experts in the Netherlands (as discussed in subsection 2.2.1).

Table 33. List of BIM uses for construction logistics

BIM uses for construction logistics	
1	Data exchange with other project partners/ project disciplines
2	Generating quantities from the 3D model
3	Coupling of 3D model to a planning (4D modeling)
4	Cost estimation with the 3D model (5D modeling)
5	Labelling and numbering of objects for production, installation and logistics
6	Positioning via laser and machine guidance techniques
7	3D coordination (management of subcontractors and suppliers)
8	Support of lean sessions with the model
9	Monitoring of logistics via RFID-tags and/or barcodes
10	3D modeling of temporary structures
11	Coupling of BIM with traffic simulation models
12	Coupling of BIM with GIS
13	Optimizing logistics for multiple projects within the same region

1 DATA EXCHANGE WITH OTHER PROJECT PARTNERS/ PROJECT DISCIPLINES

Description and possible benefits

A process in which the model is used for exchanging data. The model serves as a repository of data that can be retrieved by multiple applications used by project partners/ project disciplines working in the same project (Eastman et al., 2011). Data exchange through BIM could eliminate manual copying of partial project data, which could lead to the following benefits for construction logistics (Eastman et al., 2011):

1) It encourages iteration during design, which is necessary for finding the optimal alternative for construction logistics
2) It reduces errors and inconsistency of information, which leads to smooth execution of activities
3) It increases automation of business processes, which reduces cycle times and overall time required for construction operations.

Can support the following logistics tasks and address the following common bottlenecks

During the **design phase**, this BIM use can support the **designer** in analyzing alternative structural designs and material utilization. It can also support the **designer, subcontractors and suppliers** in incorporating the use of prefabrication in the design. During the **execution phase**, this BIM use can support the **prime contractor** in updating schedules and plans, and in managing documentation. When **subcontractors and suppliers** are given access to the model, this BIM use can support them in preparing the Bill of Materials, engineering design and creating shop drawings. Throughout the construction process, this BIM use can address the long search for requisite information, incorrect documents and reduce errors and inconsistency of information.

Interoperability of the BIM tools and BIM platforms utilized by the project partners/ project disciplines is critical to achieve easy and reliable exchange of data (Eastman et al., 2011). When BIM data are exchanged between various tools and platforms, data interoperability ensures that no information is lost in the exchange.

2 GENERATING QUANTITIES FROM THE 3D MODEL

Description and possible benefits

A process in which the model is used to generate the quantity takeoff of materials. Quantities can be automatically extracted from the model; most BIM tools can count the number of items, and calculate spatial quantities – like length, area, and volume – using the element's geometric properties (Eastman et al., 2011). The information can be used in all phases of the project: (preliminary) cost estimation, scheduling, purchasing, and cost reporting.

Extracting the information from the 3D model depends on how elements are modeled and the measurements parameterized (Hartmann, Van Meerveld, Vossebeld, & Adriaanse, 2012). For example, when the model contains detailed element information (such as the manufacturer's code, and weight per meter), then a quantity takeoff of specific items can be generated by identifying the relevant components, extracting the required quantity, generating the item description, and counting the number of occurrences.

Can support the following logistics tasks and address the following common bottlenecks

During the **design phase**, this BIM use can support **prime contractor** in the preparation of logistics assessment. During the **preparation/ project engineering phase**, this BIM use can support the **prime contractor** in preparing the Bill of Materials and the schedules and charts of labor and equipment utilization. During the **execution phase**, if the model is kept up-to-date, this BIM use can support the **prime contractor** in adjusting orders to current demand for resources. Throughout the construction process, prime contractors, designers, subcontractors and suppliers can visualize both area and location of available space on site through this BIM use, which can be valuable for planning of logistics activities.

3 COUPLING OF A 3D MODEL TO A PLANNING (4D MODELING)

Description and possible benefits
A process in which the 3D geometries and location of objects in the model are linked to the timings of their production, delivery or construction (4D modeling). The resulting model can be used for a number of tasks, which include (Computer Integrated Construction Research Program, 2010; Eastman et al., 2011):

1) Communication – the 4D model is used to effectively communicate the sequence of activities in a visual manner (time and space aspects).
2) Phase planning – the 4D model is used to plan and show the construction sequence and space requirements on site.
3) Site utilization planning – the 4D model is used to visually represent both temporary and permanent facilities on-site together with the schedule.
4) Quantifying materials space requirements – the 4D model is used to quantify and represent material space requirements for each task, construction section, time unit, on a numerical value basis (e.g. m^2, m^3) and on a geometrical parameter basis (e.g. width, length, height).
5) Progress checking and monitoring – the 4D model is updated with the current status of the project and is used to compare the progress against the schedule.

An advantage of model-based scheduling is that it captures the spatial components related to activities, and directly links activities with the design (Computer Integrated Construction Research Program, 2010). Through this link, the schedule can remain in sync with the design, and stakeholders are able to easily understand the schedule, evaluate its feasibility and its impact on logistics.

Can support the following logistics tasks and address the following common bottlenecks
During the **design phase**, this BIM use can support the **prime contractor** in preparing the production design (construction sequence)/ phase planning. This BIM use can also support the **prime contractor**, **designer**, and other project partners in optimizing design and construction operations. During the **preparation/ project engineering phase**, this BIM use can support the **prime contractor** in preparing schedules and charts of labor and equipment utilization and planning of site activities. During the **execution phase**, this BIM use can support the **prime contractor** in site utilization planning, updating schedules, work progress monitoring, and planning and coordinating horizontal and vertical transportations on site. Throughout the whole construction process, this BIM use can address information needs regarding spatial and temporal requirements of scheduled tasks, effective communication and scheduling between prime contractor and subcontractors/suppliers, and visualize impact of procurement delays.

4 COST ESTIMATION WITH THE 3D MODEL (5D MODELING)

Description and possible benefits
A process in which the model is used to generate quantity take-off and cost estimate, and provide the effects of additions and changes on cost in a timely manner (Eastman et al., 2011). Model-based estimation reduces uncertainty associated with material quantities, resulting to improved accuracy and reliability within the estimate (Eastman et al., 2011; Hartmann et al., 2012). Visualization reduces misinterpretation of the design, which in turn reduces errors in estimating. It is worthy to note that the accuracy and level of detail of the estimate depend on the level of detail of the overall building information model.

For this process, it is important the contents of the models are aligned with the existing formal methods used for estimating in an organization (Hartmann et al., 2012). In addition, BIM provides only a small part of the information necessary for cost estimating. No BIM tool can automatically deliver a full cost estimate from a model. Estimators perform a critical role in assessing conditions in the project that affect cost, and in calculating labor, (temporary) material, equipment and indirect costs (Eastman et al., 2011).

Can support the following logistics tasks and address the following common bottlenecks
During the **design phase**, this BIM use can support the **designer** in preparing material requirement specifications. This BIM use can also support the **prime contractor** in conducting feasibility studies of logistics concepts. During the **preparation/ project engineering phase**, this BIM use can support the **prime contractor** in preparing schedules and charts of labor and equipment utilization, selecting subcontractors and suppliers, and preparing material procurement planning. During the **execution phase**, this BIM use can support the **prime contractor** in work progress monitoring and adjusting orders to current demand for resources.

5 LABELLING AND NUMBERING OF OBJECTS FOR PRODUCTION, INSTALLATION & LOGISTICS

Description and possible benefits
A process in which objects in the model are labelled and numbered. The unique ID can be labelled and numbered for each component, for a group of components required for installation, or for a group of components required for production or purchasing (Ala-Risku & Kärkkäinen, 2006). Labelling and numbering allow for tracking-based inventory transparency.

Can support the following logistics tasks and address the following common bottlenecks
During the **preparation/ project engineering phase**, this BIM use can support the **prime contractor**, **subcontractors and suppliers** in production and erection sequence planning.

6 POSITIONING VIA LASER & MACHINE GUIDANCE TECHNIQUES

Description and possible benefits
A process in which (Eastman et al., 2011):

1) The information in the model is extracted into a machine-guided equipment to guide and verify the grading and excavation activities
2) Data from laser measurement devices of field activities are reported back to BIM for verification and to detect field errors.

These techniques rely on various technologies and GPS.

Can support the following logistics tasks and address the following common bottlenecks
During the **execution phase**, this BIM use can support the **prime contractor**, **subcontractors and suppliers** in construction and installation activities.

7 3D COORDINATION (MANAGEMENT OF SUBCONTRACTORS & SUPPLIERS)

Description and possible benefits
A process in which the model is used to manage subcontractors and suppliers. Information in the model can be used as input by suppliers for digital fabrication, and information can be added to the model by

subcontractors and suppliers (Eastman et al., 2011). Model-based coordination of subcontractor's and supplier's activities and designs can save time and reduce errors (Eastman et al., 2011; Trebbe et al., 2015).

When detailed design information is available in the model, subcontractors and suppliers can use this information for generating detailed information for manufacturing, fabrication and erection, and for producing shop drawings (Aram, Eastman, & Sacks, 2013). In addition, 3D coordination reduces design coordination errors; conflicts can be identified before the installation of components on site (Eastman et al., 2011). An added advantage of this use is the increased possibility for preassembly and prefabrication (Eastman et al., 2011).

Can support the following logistics tasks and address the following common bottlenecks
During the **design phase**, this BIM use can support the **prime contractor**, **designer**, and other project partners in optimizing design and construction operations. During the **preparation/ project engineering phase**, this BIM use can support the **subcontractors and suppliers** in engineering design and preparation of shop drawings.

8 SUPPORT OF LEAN SESSIONS WITH THE MODEL

Description and possible benefits
A process in which the model is used to support the application of lean concepts. The application of lean construction techniques requires careful coordination between the prime contractor and the subcontractors and suppliers (Eastman et al., 2011).

The BIM use can facilitate leaner construction through (Sacks, Koskela, Dave, & Owen, 2010):

1) Greater degrees of prefabrication and preassembly. Highly automated generation of production and erection information, and faster production of shop drawings shorten production cycle times, leading to greater degrees of prefabrication and preassembly.
2) Improved workflow stability trough a priori identification and resolution of spatial, logical or organizational conflicts due to virtual construction.
3) Enhanced teamwork
4) Just-in-time production, just-in-time delivery and just-in-time arrival of people and equipment.

Can support the following logistics tasks and address the following common bottlenecks
During the **design phase**, this BIM use can support the **designer** in analyzing alternative structural designs and material utilization. During the **preparation/ project engineering phase**, this BIM use can support the **prime contractor** in waste management planning and preparing supply plan and schedule. During the **execution phase**, this BIM use can support the **prime contractor**, **subcontractors and suppliers** in planning and coordinating deliveries. Throughout the construction process, this BIM use can shorten engineering lead times and response times along the supply chain, level plant production, reduce material and time buffers, and facilitate a more flexible approach to daily construction activities.

9 MONITORING OF LOGISTICS VIA RFID-TAGS AND/OR BARCODES

Description and possible benefits
A process in which the model is coupled to radio frequency identification (RFID) or wireless sensor networks (WSNs) to automatically collect and share information regarding the material and component flow throughout manufacturing, shipping, delivery and erecting processes (Eastman et al., 2011). BIM

components linked to RFID-tags can automatically update work status and provide rapid feedback on field progress and installation.

The model is directly linked to wireless technology in the construction site. Logistics of various construction elements can be monitored and directed through the use of devices for scanning RFID-tags and barcodes. In this manner, other building processes can be aligned with the locations of elements, which are made visible in the model. In addition, it is also possible to display information regarding the status of the elements, such as 'in production' or 'in storage' (Eastman et al., 2011; Shin, Chin, Yoon, & Kwon, 2011).

Can support the following logistics tasks and address the following common bottlenecks
During the **execution phase**, this BIM use can support the **prime contractor** in work progress monitoring, updating schedules, and adjusting orders to current demand for resources. This BIM use can address lack of transparency and visibility to materials inventory (on-site), and provide the prime contractor, subcontractors and suppliers with comprehensive and reliable information on material availability.

10 3D MODELING OF TEMPORARY STRUCTURES

Description and possible benefits
A process in which the design software for 3D systems is used to design and analyze complex (temporary) constructions (for example, formwork, temporary constructions or glassware). This can improve planning and feasibility (Computer Integrated Construction Research Program, 2010).

Can support the following logistics tasks and address the following common bottlenecks
During the **design phase**, this BIM use can support the **prime contractor** in conducting feasibility studies of logistics concepts. During the **preparation/ project engineering phase**, this BIM use can support the **prime contractor** in site utilization planning.

11 COUPLING OF BIM WITH TRAFFIC SIMULATION MODELS

Description and possible benefits
A process in which the model is linked to traffic simulation software to visualize and analyze the effects of (planned) construction activities on traffic, for example, the effects on traveling time through construction area, traffic congestion, and traffic safety. Through this process, the schedule can be adjusted to minimize nuisance to traffic.

Can support the following logistics tasks and address the following common bottlenecks
During the **design phase**, this BIM use can support the **prime contractor** in conducting feasibility studies of logistics concepts and phase planning.

12 COUPLING OF BIM WITH GIS

Description and possible benefits
A process in which the model is coupled to Geographic Information System (GIS) and used to visualize the supply chain process and monitor the flow of materials, by tracking components that are identified with its corresponding ID in the model. This can also be utilized to determine and evaluate the most cost-efficient solution for transport and storage of materials and components. The integration of BIM and GIS could lead to substantial benefits to the planning process. "BIM provides geometry, spatial relationships, and

quantities of building components, GIS can use them to support a wide range of spatial analysis used in an early phase of the procurement process, and BIM can visualize the results of the GIS analyses in a 3D virtual world." (Karan & Irizarry, 2015, p. 1)

GIS contains the location of suppliers, and is used to determine the most profitable solution to the delivery (including transportation and storage) of materials to the construction site. The actual status of each object to be purchased can be visualized through the coupling of BIM with GIS. The availability of materials and their end locations are clearly displayed, which facilitates monitoring and allows for transparency of purchasing and delivery (Irizarry & Karan, 2012; Irizarry et al., 2013).

The data required from the model are the component's ID, geographic information, its quantities and properties. With respect to GIS, data required are location of suppliers, transportation mode(s), warehouse capacity, and product characteristics. Other information required for the integration of BIM and GIS include: schedule of material delivery, components and their installation locations, and schedule of relevant activities (Irizarry & Karan, 2012; Irizarry et al., 2013).

Can support the following logistics tasks and address the following common bottlenecks
During the **design** phase, this BIM use can support the **prime contractor** in analyzing the feasibility of logistics concepts. During the **preparation/ project engineering phase**, this BIM use can support the **prime contractor** in planning site activities, material storage planning, preparing supply plan and schedules. During the **execution phase**, this BIM use can support the **prime contractor** in work progress monitoring, and planning and coordinating deliveries. This BIM use can provide in-depth cost and time analyses for evaluating trade-off between transportation, inventory, and production costs. Moreover, this BIM use can provide comprehensive information on material availability, transparency and visibility to material inventories on site and other stages of the supply chain (material tracking). Warnings can also be issued from the BIM-GIS module to avoid late procurement of resources.

13 OPTIMIZING LOGISTICS FOR MULTIPLE PROJECTS WITHIN THE SAME REGION

Description and possible benefits
A process in which models of multiple construction projects within the same region are combined. The combined models can then serve as the basis for the 'control-tower' concept for the construction, wherein the logistics of various projects can be planned, optimized and controlled.

Appendix D. Case description: Boekelo Bridge Hengelo

D.1.1. Prologue

The case-study was the design phase of the project, Boekelo Bridge in Hengelo. The scope of the case-study was the 1st layer relationship (client – prime contractor relationship). The organizations involved in the study were the client and the prime contractor.

Both the design and replacement of the bridge were contracted to a single party with an integrated contract (Design and Build). The project started in August 2017 and is planned to be completed by January 2019, with a budget of € 8 million. The contract was awarded through the MEAT (most economically advantageous tender) method. The three MEAT criteria with their corresponding fictional price reduction are listed in Table **34**.

Table 34. MEAT criteria in the Boekelo Bridge project.

MEAT criteria	Max. fictional price reduction in €'s
Architectural and esthetic quality	3.000.000
Innovation	1.000.000
Construction duration	250.000

The client has an interest to stimulate innovations in the region. For this purpose, the client asked the prime contractor to incorporate three innovations in the project. An innovation in this project was defined as: "The development and successful implementation of new ideas, products or processes by the design and construction of the bridge."

The innovations were classified either as a product or a process innovation. A product innovation concerns an innovation aimed at a substantial improvement of the functionality of the bridge, the expansion of the functionality of the bridge and/or the improvement of the (technical) performance of the bridge. A process innovation concerns an innovation for the realization process of the bridge. Examples include innovative solutions leading to a substantial reduction of the construction duration, construction costs and/or safety.

The innovations were also classified according to the degree and level of the innovation. Four degrees of innovation were defined: radical, substantial, incremental, and creative. Radical innovations are new and limitedly applied to the global market and with new technology. Substantial innovations are new and limitedly applied in the Dutch market and with new technology. Incremental innovations are substantial improvements to existing solutions for bridges or for the existing realization process of bridges. Creative solutions are achieved through a combination of existing solutions for bridges or of existing realization processes of bridges.

Three levels of innovation were defined: system, modular, and component level. These levels could apply for both product and process innovations. For product innovations: a system innovation is an innovative solution for the bridge as a whole; a modular innovation is an innovative solution for a main part of the bridge; and a component innovation is an innovative solution for a component belonging to the bridge. For process innovations: a system innovation is an innovative solution for multiple work packages; a modular innovation is an innovative solution for one work package; and a component innovation is an innovative solution for a process within one work package.

Each degree and level of the innovation corresponded with a score. Radical innovations at system level score the highest and receive the maximum fictional price reduction, while creative solutions at component level score the lowest and receive the minimum fictional price reduction.

For the MEAT criterion Innovation, the prime contractor scored the maximum fictional price reduction for the three innovations it incorporated in the project (Table **35**).

Table 35. Three innovations incorporated in the Boekelo Bridge project.

Innovation	Description
Mixed reality for the whole construction process, *substantial process innovation at system level*	A substantial process innovation was achieved by linking new and existing technologies. Mixed reality is the merging of digital and physical worlds to produce visualizations where the digital and physical objects co-exist. By visualizing the construction project and related processes in the physical world, stakeholders can develop more intuitive understanding of the project, communicate with each other more effectively, and prevent errors before they occur on site. Through these, efficiencies in the construction process can be achieved.
Solar panels in the road surface, *radical product innovation at component level*	Solar panels are not innovations by themselves. However, the application of solar panels in the road surface has never been successfully implemented before, therefore, it is considered as a radical product innovation. By incorporating solar panels in the road surface, the bridge will generate the energy necessary for the lighting, making it energy-neutral.
Low-baked powder coating for the bridge, *incremental product innovation at component level*	The low-baked powder coating will be applied to the handrail posts of the bridge (component). The aim of the innovation is to increase the lifespan of the posts and to reduce the required maintenance.

In addition to stimulating innovations in the region, the client has an interest in ensuring that the bridge is realized within the subsidy period. The client also values that there is little nuisance to the environment during the realization of the bridge. For this purpose, the prime contractor was asked to indicate the number of calendar months that they would like to deliver the work earlier than the delivery date of 01 June 2019. The prime contractor had the choice between one calendar month up to and including five calendar months earlier, in which one calendar month equals a fictional price reduction of € 50.000, with a maximum fictional price reduction of € 250.000 for this MEAT criterion.

For the MEAT criterion Construction duration, the prime contractor proposed to deliver the work five calendar months earlier, on 01 January 2019. For this, the prime contractor received the maximum fictional price reduction of € 250.000.

In the next paragraphs, the logistics (information) needs, BIM scenarios and bottlenecks experienced by each party will be explained in detail.

D.1.2. Client

Logistics (information) needs

The project is in an industrial area and the bridge crosses the Twente Canal. Nuisance to road and waterway traffic was not a critical issue for the client in this project. The client evaluated that there are enough alternative routes for the road traffic around the Boekelo Bridge. Two bridges parallel to the Boekelo Bridge could serve as alternatives for the traffic passing Boekelo Bridge. The client also evaluated that there will be minimal nuisance to the waterway traffic during the replacement of the bridge. Based on the above reasons, the client decided to close the bridge and redirect all road traffic away from the bridge for the whole construction period. To minimize the nuisance to road traffic, the client decided to stimulate the prime contractor to reduce the duration of the construction period. This was achieved through the MEAT criterion for construction duration.

D.1.3. Prime contractor

Logistics (information) needs

The construction of the new bridge will start after the old bridge has been removed. All traffic will be rerouted during the duration of the construction. Therefore, there will be no traffic passing through the project area and the prime contractor may work on the bridge without restrictions on the time slots related to traffic. However, the prime contractor still needs to consider the shipping traffic passing through the Twente Canal.

The logistics tasks of the prime contractor during the design phase are the analysis of alternative materials utilization and the preparation of material requirement specifications and production design. Consequently, the prime contractor needs to know the quantities and specifications of the materials. The information is available from the designer, and is needed by the prime contractor for planning and purchasing.

Specifically, for this bridge project, the prime contractor would make use of prefabricated bridge components. The prime contractor must ensure that the dimensions and quantity of the components are accurate and error-free, and that the joints and interfaces of the components match with each other. For this, it is necessary to coordinate with the designer and the steel subcontractor to ensure that the design and shop drawings are aligned.

The prime contractor incorporated three innovations in the project (see Table 35). One of the three innovations is the application of mixed reality for the whole construction process. This means that the prime contractor needs a visualization of the existing conditions (physical world) and a building information model of the construction project and process. The model of the construction process will be used to arrange the installation sequence of the bridge components and to align the production and delivery schedules according to this installation sequence.

The prime contractor also needs information on the sizes of the prefabricated beam bridge components to be transported to the location. Since the bridge components can be bulky, the prime contractor is interested to know the maximum size of each bridge component that can be accommodated either by the roads to the project area or by the waterways. The prime contractor would also like to know the transportation modes, load capacity of lifting equipment, storage options, and transportation routes that would result to the least cost and time for the shipping of the new bridge into the project area.

Appendix E. Case description: N31 Highway Harlingen

E.1.1. Prologue

The case-study is the construction phase of the project, N31 Highway in Harlingen. The project involved the widening and realigning of the existing N31 Highway. In addition, five new viaducts and one new aqueduct were placed along the trajectory. Both the design and construction of the highway were contracted to a single party (Design-Build contract), through the MEAT (most economically advantageous tender) method. The project ran from March 2014 to December 2017, with a budget of € 146 million.

Logistics was an important aspect in this project. N31 is a national highway with important connections to the underlying road network and bicycle lanes, and an intersection with a local rail. Nuisance to the users of the highway, underlying road network and bicycle lanes must be kept at a minimum. In addition, access to the businesses, schools and hospital during the construction phase must be maximized.

One of the MEAT criteria used to compare the bids during the procurement phase was related to logistics. For this criterion: Minimize Nuisance, the prime contractor had to propose strategies to mitigate the nuisance to the road traffic and the surrounding environment. The proposed strategies were evaluated under the following aspects (Table **36**):

Table 36. Criteria for evaluating the MEAT criteria in the N31 Highway project.

Category	Nuisance evaluation aspects
Nuisance to road traffic	Number of weekends used for conducting construction works
	Number of nights used for conducting construction works
Nuisance to the surrounding environment	Accessibility, livability, safety and communication during the construction phase
	Extent of use of the underlying road network by construction related traffic
	Prevention of nuisance and damage [out of scope: not related to logistics]
	Prevention of complaints [out of scope]

To mitigate the nuisance to road traffic, the prime contractor proposed to implement the following strategies (Table **37**):

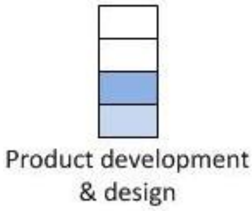
Table 37. Mitigation strategies proposed by the prime contractor.

Nuisance evaluation aspects	Nuisance mitigation strategies
Number of weekends used for conducting construction works	[Confidential]
Number of nights used for conducting construction works	[Confidential]
Accessibility, livability, safety and communication during the construction phase	The prime contractor proposed to maintain all existing roads and bicycle lanes. To minimize the nuisance to the users of the highway caused by construction traffic, the prime contractor proposed to build an overpass to separate the construction traffic from the public.
Extent of use of the underlying road network by construction related traffic	The prime contractor proposed to avoid the use of the underlying road network for construction related traffic. Instead, construction traffic would make use of the N31 highway, and of its own temporary roads.

E.1.2. Levels of supply chain integration

The scope of the case-study included the 1st layer (client – prime contractor) and 2nd layer (prime contractor – designer, subcontractors and suppliers) relationships. The organizations involved in the study were the client, prime contractor, designer, reinforcement steel subcontractor, earthmoving subcontractor, and concrete mix supplier. The level of supply chain integration of the prime contractor with the designer, subcontractors and suppliers will be described below.

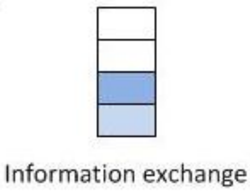
The aspect 'partner sourcing and collaboration strategy' was integrated. The prime contractor employed its in-house specialist departments and sister companies. The prime contractor's mother company has financial ownership of the designer and one of the subcontractors involved in the case-study (earthmoving subcontractor). The other two subcontractors have a long-term relationship with the prime contractor, either as a strategic partner or as a sister company. The reinforcement steel subcontractor is a strategic partner of the prime contractor, while the concrete mix supplier is a sister company of the prime contractor.



The aspect 'product development and design' was loosely coupled. This is indicated by the early involvement of the subcontractors in the project, but they were not fully involved in the design. During the tender phase, the reinforcement steel subcontractor advised the prime contractor on how to design the reinforcement steel for faster installation. The earthmoving subcontractor advised the prime contractor on major construction methods for faster soil extraction.

However, changes to the design and construction methods were not coordinated with the subcontractors, indicating that they were not fully involved in the design. The resulting design did not fully incorporate the advice of the reinforcement steel subcontractor. The earthmoving subcontractor was also not involved in the decision to switch from anchor sheet pile to strut retaining wall, which had major implications for the earthmoving subcontractor's activities.

The aspect 'planning and logistics control' was loosely coupled. The focus of the logistics was more on inventory control than on inventory reduction, which is characteristic of a loosely coupled supply chain. Operational planning was jointly coordinated through lean planning sessions with subcontractors and suppliers. However, logistics and transport from the subcontractors and suppliers were separate and need to be coordinated by the prime contractor. In addition, there was no advanced ICT system implemented for joint planning to enable advanced logistics strategies, such as just-in-time delivery.



The aspect 'information exchange' was loosely coupled. Characteristics of a loosely couple supply chain for the aspect 'information exchange' that were present in this project include low transparency and visibility of information. In addition, there are no shared information systems or an information database that is accessible to the subcontractors and suppliers, or vice versa. Information flows via email correspondence and personal communication.

Within the company, the flow of knowledge and information is fostered between the departments (prime contractor, designer and earthmoving subcontractor) in a joint information system. Employees of the company are trained in the fields of information technology and lean processes, which are not necessarily project-specific.

E.1.3. Client

Logistics (information) needs

During the construction phase, the client is in dialogue with the prime contractor regarding the progress of the activities and the prime contractor's compliance to the agreements made at the beginning of the project. Due to the delay in the schedule, part of the dialogue between the client and the prime contractor is the renegotiation of the agreements to find solutions to the delay in the schedule.

One of the agreements that the client and the prime contractor are renegotiating is the traffic management plan proposed by the prime contractor in his MEAT plan. Information needs of the client for these tasks include the changes in the traffic management plan, their effect on the existing road network, and the needs of the public affected by the construction activities to evaluate which changes are acceptable.

Barriers for implementing BIM

The client did not implement any BIM uses in this project. An important barrier for the client was its role and responsibilities in the project. The client expressed that, in relation to logistics, its role was to specify the requirements that the prime contractor must satisfy. It was the prime contractor's responsibility to show that he complied with these requirements.

Another barrier was the perception of the client of the benefits of BIM. The benefits of BIM perceived by the client is related to Asset Management. The client perceived the benefits of BIM for logistics to a lesser degree.

Bottlenecks

One of the bottlenecks during the construction phase was the delay in completion of construction activities by the prime contractor. The delay in completion of activities may lead to prolonged nuisance and economic loss for the client and users of the highway.

The delivery of data for project handover was also problematic. One major cause of this problem was the novelty of the technology. The delivery of project asset information occurred through the COINS system, which was new for both the client and the prime contractor. The prime contractor had issues with setting up the database and filling in the information according to the COINS system.

Possible BIM scenarios and their benefits

To address the bottlenecks mentioned above, the client can request the (potential) prime contractor to submit a 4D model linked to a traffic simulation model of the road network affected by the project. For this, the client should provide the base traffic simulation model to the (potential) prime contractor(s), which the prime contractor can use to test the impact of his logistics plan on the surrounding roads.

Possible incentives for implementing BIM – 1st layer relationship

One possible incentive that can be implement in this project is to select organizations based on their BIM competence and readiness. During the tender phase, candidates can be screened for suitability, through several criteria related to their financial and economic capacity, and their technical and professional competence. These suitability criteria can include criteria on the candidate's BIM competence and readiness. Candidates who satisfy these criteria will be invited to bid, while those who fail to satisfy will be excluded from the bid. This creates an incentive for the prime contractor to invest in BIM and to develop BIM competencies.

The prime contractor also expressed a preference for selecting organizations based on their BIM competence and readiness. The prime contractor cited that this incentive gives construction companies that have invested in BIM gain an advantage compared to their competitors and provides them with an opportunity to earn their investments in BIM. In addition, this incentive will also motivate organizations to (further) develop their BIM competence and readiness.

Another incentive is to apply MEAT criteria related to BIM and logistics. As explained in the New Lock Terneuzen case study, applying MEAT criteria related to BIM and logistics will motivate prime contractors to implement BIM as they are rewarded a higher chance of winning the tender.

In this project, the evaluation aspects for the MEAT criterion "Minimize Nuisance" should be modified to include the analysis and logistics plans that support the mitigation strategies proposed by the prime contractor. In other words, the client should not only specify the performance criteria, but also the general underpinnings of the prime contractor for achieving these performance criteria. For example, the client can request a traffic simulation model that simulates the planned construction-related traffic intensity and proposed mitigation strategies, along with the extent of use of the underlying road network by construction related traffic.

A precondition for this incentive is that additional time should be given to the prime contractors to prepare and develop their bids. Since more activities are shifted to the tender phase, the duration of the tender phase must also be extended. However, extending the duration of the tender phase might require changes to the standard procurement procedures and/or regulations.

E.1.4. Prime contractor

Logistics (information) needs

The construction of the N31 Highway was a strongly sequential process. It was composed of the successive activities of draining, digging, grading, reinforcing and paving. For portions of the highway composed of tunnels or viaducts, additional activities of placing of formworks, placing of reinforcement steel, concrete pouring, and removing of formworks were also included. For each highway section, these sequential activities were conducted. When there was a delay in one of these activities, the rest of the activities were also delayed.

During the construction phase, the logistics tasks of the prime contractor included work progress monitoring, coordination of its activities and those of the subcontractors and suppliers, and managing information flows. The prime contractor needed to coordinate that the activities of the subcontractors responsible for the activities to prevent errors from occurring on site. Subcontractors related to this critical path must be kept up-to-date and the necessary resources must be available on time.

Consequently, the prime contractor needed access to comprehensive information on the availability of materials and equipment for each task. Furthermore, the prime contractor needed comprehensive information on the material, equipment, and spatial needs of the subcontractors and suppliers. Aside from information on the location, time and duration of the activities of the subcontractors, the prime contractor also needed to know which materials and equipment must be on site and how much space must be made available to accommodate them. Ideally, the prime contractor must have this information two weeks before the planned activity was scheduled, to prepare the site utilization schemes and coordinate the flow of materials.

Incentives and barriers for implementing BIM

In this project, no BIM scenarios were implemented by the prime contractor. Although there were incentives to motivate the prime contractor to implement BIM, these did not lead to BIM implementation. This will be explained further below.

The first possible incentive was the integrated contract type. The integration of design and construction could increase the benefits of BIM for the prime contractor, which could motivate the use of BIM. However, this possible incentive did not lead to BIM implementation by the prime contractor. From the beginning of the project, the prime contractor chose not to implement BIM. The reason for this choice was not identified by the researcher.

The second possible incentive was the MEAT criterion: Minimize nuisance. This MEAT criterion rewards the prime contractor for minimizing nuisance with a higher chance of winning the tender, thereby motivating the prime contractor. However, this did not lead to BIM implementation. The reason was that the prime contractor did not implement BIM during the tender phase of the project.

The last possible incentive were penalties imposed by the client for not fulfilling the agreements related to the MEAT criterion: Minimize nuisance. The penalty creates an incentive for the prime contractor to keep track of the progress of the works and minimize the nuisance. In turn, this can create an incentive for the prime contractor to implement BIM, since BIM can be beneficial for keeping the project progress on track.

However, this also did not lead to BIM implementation by the prime contractor. One of the main barriers to implementing BIM in this project was the time pressure. Instead of implementing BIM, the project practitioners opted for the working methods that they have implemented before, due to the lack of time available to learn and implement BIM in this project.

Another main barrier to implementing BIM in this project was the level of knowledge and skills of the employees with regards to BIM. This aspect, together with the level of effort required to implement BIM, impeded the implementation of BIM.

Bottlenecks

The nuisance mitigation strategy proposed by the prime contractor for the MEAT criterion Minimize Nuisance resulted to long distances travelled by the trucks (see Figure 20). Since the trucks were not allowed to use the underlying road networks, trucks often had to traverse sections of the main highway four times longer to get to and from the location of activities when transporting resources. The long distances travelled by the trucks resulted to longer transportation durations of resources to and out of the location of activities. This lowered the productivity rate of the subcontractors, which led to delays in completion of activities. Furthermore, the long distances also resulted to increased CO_2 emissions and traffic congestion on the main highway.

Figure 20. Prohibited roads for construction-related traffic.

The cramped space caused by the strut retaining walls lowered the productivity rate of the earthmoving subcontractor, leading to delays in the completion of activities. The prime contractor had to speed up the construction process by starting an additional stream of construction activities, and by working on weekends and at night to avoid incurring penalties for delayed project turnover. However, even these measures did not prevent a delay in project turnover, and the prime contractor had to pay penalties, in addition to the extra costs incurred for the measures.

The information provided by the subcontractors during the construction phase on the availability of materials and their equipment and space needs was incomplete. This aspect, combined with the fact that the prime contractor also had no access to comprehensive information on materials and equipment availability from subcontractors in the critical path, was a major bottleneck in the project. The lack of information resulted to lack of available space on site and idle times for subcontractors and suppliers, thereby increasing the cost and duration of activities.

Possible BIM scenarios and their benefits

For the development of more effective nuisance mitigation strategies, the prime contractor could implement the BIM scenario: 'Coupling of BIM with traffic simulation models', which is a process in which the model is linked to traffic simulation software to visualize and analyze the effects of (planned) construction activities on traffic, for example, the effects on traveling time through construction area, traffic congestion, and traffic safety.

The prime contractors can then use the traffic models to analyze and optimize the effects of different alternatives of their planning and traffic measures on road traffic. The quantities of material for each construction phase of their alternative plans can be exported from the 4D model to a spreadsheet. By dividing the quantities by the capacity of the chosen means of transport, the number of construction traffic flows can be determined and entered into the traffic model. By means of the traffic model, the prime contractors can adjust the mitigation measures to prevent undesirable consequences, such as longer transportation routes and larger CO_2 emissions, from occurring.

To create visibility of (site) inventories, the prime contractor could monitor logistics via RFID-tags and/or barcodes. The BIM scenario: 'Monitoring of logistics via RFID-tags and/or barcodes', is a process in which the model is coupled to radio frequency identification (RFID) or wireless sensor networks (WSNs) to automatically collect and share information regarding the material and component flow throughout manufacturing, shipping, delivery and erecting processes. BIM components linked to RFID-tags can automatically update work status and provide rapid feedback on field progress and installation.

This BIM scenario would benefit the prime contractor, subcontractors and suppliers by creating visibility to (site) inventories, which include reliable information on material availability and location on site or elsewhere along the supply chain. This technology has not yet been widely implemented in practice and can still be costly to implement. Further research is needed to investigate its use in practice, and to gain insight into the requirements for successfully implementing this technology.

Possible incentives for implementing BIM – 2nd layer relationship

The prime contractor would need the input and cooperation of the designers, subcontractors and suppliers to successfully implement the BIM scenarios described above. First, the prime contractor can select organizations based on their BIM competence and readiness. The prime contractor can look for a designer, subcontractor or supplier who can create (a part of) the BIM that is related to his expertise. This creates an incentive for the designer, subcontractor or supplier to invest in BIM and to develop the organization's BIM competencies.

Second, to motivate designers to deliver the required BIM data, the prime contractor can apply sharing of savings. Risk sharing can also be applied, but an important precondition of this incentive is that the designer is also capable of bearing the risks. Since the designer in this project was not capable of bearing the risk, sharing of savings is a more suitable incentive. One way to generate savings is through value engineering. During contract formulation, the prime contractor and designer can agree to apply value engineering and stipulate in their contract a percentage of distribution of savings. The savings gained through value engineering can be used to pay for the extra modeling costs. The remainder of the savings would also be distributed among the prime contractor and the designer (according to a predetermined percentage of distribution).

E.1.5. Designer

Logistics (information) needs

During the construction phase, the designer did not have any logistics-related tasks. From the interview with the head designer, the logistics-related tasks of the designer during the design phase were to analyze alternative structural designs and materials utilization; and to analyze the effects of (preliminary) design choices on construction logistics by coordinating the design choices with the prime contractor.

Consequently, the designer required the judgement of the prime contractor on the impact of changes in the design on construction logistics. When changes to the design are made, the designer must communicate the design to the prime contractor. Likewise, the prime contractor must evaluate the impact of the changes to the construction process and inform the designer on the acceptability of the design changes.

Incentives and barriers for implementing BIM

In this project, no BIM scenarios were implemented by the designer and there were no 3D models created. The prime contractor and designer were integrated in the aspect of partner sourcing and collaboration strategy, which could motivate the designer to implement BIM. However, this did not lead to BIM implementation.

One of the main reasons cited for not implementing BIM was that it was not requested by the prime contractor. There were no external motivating factors present in the project. It can also be concluded that personal motivation from the designer was also inadequate to motivate the designer to implement BIM.

Bottlenecks

During the later stages of the design phase, a change was made in the design of the construction pit. A shift was made from anchored retaining walls to strut retaining walls. The designer coordinated this change with the prime contractor to evaluate its impact on the construction process. At the time, the prime contractor decided to implement the design change.

However, this change had considerable impact on the duration of earthmoving activities. The strut retaining walls obstructed the vertical space available to the cranes when digging the soil and loading the soil in the trucks. This greatly reduced the productivity rate of the earthmoving subcontractor and prolonged the duration of the digging and loading activities. This resulted to delays in other activities and the completion of the project, since highway construction is a sequential process composed of draining, digging, grading, placing of formworks, placing of reinforcing steel, and concrete pouring.

Possible BIM scenarios and benefits

To resolve the bottleneck described above, the prime contractor should hold design review meetings involving the subcontractors of activities in the critical path, using the 4D model. The 4D model is used to effectively communicate the design and sequence of activities in a visual manner (time and space aspects). Through this, the prime contractor, subcontractors and suppliers are able to easily understand the design and schedule, evaluate its feasibility and its impact on logistics. The use of 4D models in design review meetings would greatly benefit the prime contractor, as it could prevent failures during the construction phase.

E.1.6. Subcontractors and suppliers

Logistics (information) needs

The agreements made by the prime contractor with the client within the Less Nuisance plan were translated to agreements made by the prime contractor with the subcontractors and suppliers through the purchasing contract. In the purchasing contract, the prime contractor and subcontractors/suppliers agree on a Logistics Plan, which was an attachment to the purchasing contract. The Logistics Plan laid out which public roads were off-limits and for which periods.

During the construction phase, the subcontractors and suppliers required information regarding the upcoming material needs of the prime contractor, and to align and level the production across numerous projects. Project leaders of the subcontractors that were involved in this specific project required access to comprehensive information on the status of materials in their supply chain to plan and coordinate the delivery of resources to this project.

Furthermore, subcontractors and suppliers needed to coordinate their activities with other subcontractors and suppliers that have an interface with their activities. For example, the earthmoving subcontractor needed to coordinate with the crane operator and the strut retaining walls subcontractor to align the removal of the strut retaining walls with their soil digging activities.

Incentives and barriers for implementing BIM

In this project, no BIM scenarios were implemented by the subcontractors and suppliers. The earthmoving subcontractor, reinforcement steel subcontractor, and concrete mix supplier had an integrated level of partner sourcing and collaboration strategy with the prime contractor, which could increase the personal motivation of these subcontractor to implement BIM. However, this facilitating incentive alone could not lead to BIM implementation.

First, although practitioners of the subcontractors and suppliers have received BIM training provided by the prime contractor, and the subcontractors and suppliers perceive benefits of BIM, their own organizations have not implemented BIM yet. Therefore, they did not have the necessary hardware and software to implement BIM in this project. This aspect, combined with the lack of external motivation, postponed the implementation of BIM by the subcontractors and suppliers.

Second, the time pressure experienced in the project was a barrier for the subcontractors and suppliers to implement BIM for the first time. The subcontractors and suppliers perceived a lack of time to learn and implement BIM in this project, and therefore, they opted to implement the ICT that they have used before.

Last, another barrier for the subcontractors and suppliers for implementing BIM was that the prime contractor did not implement BIM. There was no 3D model available for the subcontractors and suppliers to use or build upon.

Bottlenecks

The subcontractors and suppliers relied on their experience and memory when communicating their spatial and equipment needs with the prime contractor. Their reliance on experience and memory alone was prone to error. They lacked access to comprehensive information on materials and equipment needs of their own activities, which led to incomplete information provided to the prime contractor. During meetings with project leaders of subcontractors and suppliers, the project leaders often had to consult with their on-site laborers or call their project engineers to obtain the status of the materials.

When incomplete information regarding their material, equipment and spatial needs were provided to the prime contractor, “unexpected” materials and equipment would take up more space on the site, which blocked other subcontractors from conducting their activities. This would result to lower productivity on site, and delays to the completion of the related activities.

Another bottleneck was the subcontractor’s lack of access to comprehensive and up-to-date information on the current and planned activities. During the lean sessions, subcontractors and suppliers involved in the critical path had to collaboratively re-create the schedule for the upcoming two weeks by placing post-it notes of their activities on squares on the schedule sheets (see Figure **21**).

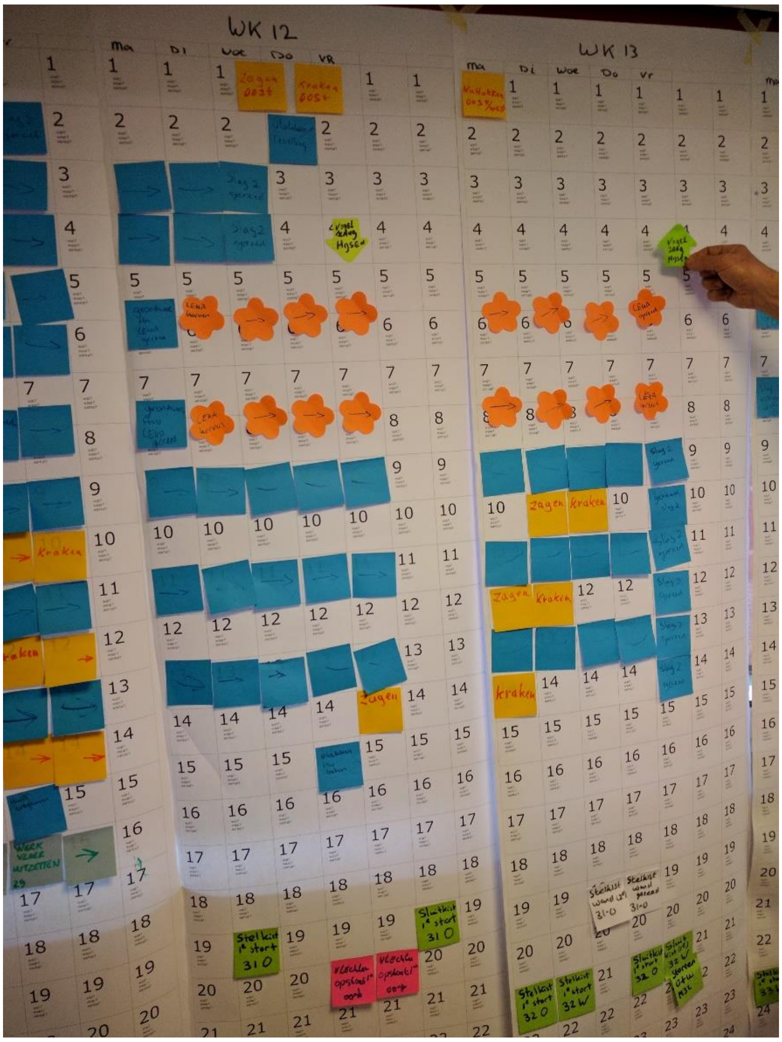


Figure 21. A schedule sheet during a lean session of N31 Highway Harlingen project.

Subcontractors and suppliers relied on their memory, and sometimes aided by bar charts, to fill-in the schedule sheets. This resulted to errors in placing of post-it notes (activities), empty time slots (missing activities), and overlapping post-it notes (representing a clash in activities). Long discussions with the involved subcontractors and suppliers were conducted to resolve the issues. However, many issues were not resolved at the end of the observed lean sessions.

Possible BIM scenarios and their benefits

To resolve the bottlenecks, the prime contractor could use 4D models to support the lean sessions. The 4D models should contain a visualization of the temporary structures and the space utilization on site. This way, the 4D models could provide information on the availability and location of materials and support deeper understanding of the construction activities and their interfaces. The 4D visualizations could trigger insights from the subcontractors and suppliers, and aid them in providing complete information to the prime contractor of their needs.

In addition, the prime contractor should provide subcontractors and suppliers access to up-to-date 4D models. This way, the subcontractors and suppliers would have access to comprehensive and up-to-date information on the current and upcoming activities.

Appendix F. Case description: New Lock Terneuzen

F.1.1. Background of the case study

The canal locks facility in Terneuzen, The Netherlands is the gateway to the ports of Terneuzen and Ghent. It connects the Western Scheldt and the Ghent-Terneuzen Canal, and is a part of the Seine-Scheldt route. On average, 1,000 ships pass through the facility each week and the number is anticipated to increase by 50% by 2020 (Maritime Research Institute Netherlands, 2015). In addition, around 70,000 vehicles (including freight traffic) pass through the roads traversing the facility each year, with the number anticipated to rise by 80% by 2020 (Walraven, Koopal, & Palsrok, 2014).

To ensure accessibility in the future, the existing canal locks facility will be expanded by replacing the middle lock with a new, larger lock. Since the facility will remain operational during the construction phase, there is a risk that the construction works will significantly reduce the accessibility of the facility. This reduced accessibility can result to increased CO_2 emissions due to longer waiting times, unsafe conditions, and millions of euros of economic loss for the users of the canal locks and for the businesses located in the facility (Maritime Research Institute Netherlands, 2015). The consequence of a delay in the completion of the project will also result to significant economic loss because of the prolonged nuisance caused by the construction activities. Therefore, the risk of nuisance is a critical risk for the client.

The case-study was the procurement phase of the project, New Lock in Terneuzen. The scope of the case-study was the 1st layer relationship (client – prime contractor relationship). The organizations involved in the study were the client and the three competing prime contractors in the competitive dialogue.

The procurement phase ran from May 2016 to August 2017, through the competitive dialogue procedure. The project is expected to run from August 2017 to August 2022, with a budget of € 753 million. The contract was awarded through the MEAT (most economically advantageous tender) method. The MEAT criteria were composed of seven criteria, listed in Table **38**.

Table 38. MEAT criteria in New Lock Terneuzen project.

MEAT criteria	Max. fictional price reduction (million €)
Geological soil structure in relation to the design and construction	10
Damage to the canal locks facility and the surrounding	40
Risk of delay to project completion	30
Risk of nuisance to shipping traffic	25
Quality risk management	25
Risk industrial automation	25
Life cycle costs	40

The client considered five important causes that would lead to nuisance to the shipping traffic during the construction phase. First, if the middle lock becomes inoperable before the new lock is operational, then the capacity of the locks facility will be reduced, which will lead to longer waiting times. The absence of the middle lock would also exacerbate the risk of nuisance when one of the remaining locks becomes inoperable because of maintenance activities or unforeseen circumstances. Second, if there is a delay in the completion of the project, then the availability of the new lock and of the terrain will be delayed, which would result to prolonged reduced capacity of the locks facility and delayed relocation of businesses back to the terrain. Third, if the contractor makes use of the canal locks facility to transport construction related materials, then the capacity of the locks facility will be reduced. Fourth and fifth, if construction related ships or activities obstruct the waterways leading to the locks and hindering the ships. On top of all these risks, the location of the project is characterized by limited space available for construction purposes.

For the TAR, various data were collected (see Table **39**).

Table 39. Data collection in TAR.

Data collection	Description
Observed meetings	Meeting for developing the 3D and 4D model requirements 3 Expert consultations
Collected artefacts	Contract documents Tender submission and evaluation guidelines Document outlining the MEAT criteria Presentation slides of each contractor used in the observed expert consultations Minutes of expert consultations Submitted risk mitigation plans by each contractor Submitted 4D models, Primavera schedules, and construction phasing drawings by each contractor Documents reporting the evaluation of the risk mitigation plans for each contractor
Interviews conducted	Contractor A: BIM manager and Construction planning and phasing manager
	Contractor B: BIM manager, Project manager, and Construction planning and phasing manager
	Contractor C: BIM manager and Construction planning and phasing manager

In the next paragraphs, the logistics (information) needs, BIM uses and bottlenecks experienced by each party will be explained in detail.

F.1.2. Prime contractor A

Prime contractor A identified passage time as the most important measure of nuisance, as it has direct economic consequences for the users of the canal locks facility. Passage time through the canal locks facility is mainly determined by the number of locks available for locking. If the middle lock became unavailable for locking, then the average passage times would significantly increase.

Consequently, the core risk mitigation strategy proposed by Prime contractor A was to keep the middle lock operational for as long as possible. Since the new lock would block the waterway of the middle lock, a new waterway must be laid around the new lock. For this new waterway to have the adequate width to accommodate the ships, the design of the objects interfacing the new waterway had to be adjusted.

The rest of the strategies proposed by Prime contractor A were grouped into three main objectives: minimization of the use of canal locks and waterways for construction purposes; creation of ample waiting places; and prevention of unexpected situations for the users. The first and second groups contained strategies related to site space utilization and logistics of materials, which had no impact on the design of the new lock, and had minimal impact on the planning at this stage. The third group contained strategies related to the communication of activities to the users of the locks facility. These did not have any impact on the design or construction method, and could be implemented during the construction phase.

In addition to these strategies, Prime contractor A also developed strategies for increasing the robustness of the planning to mitigate the risk of delay to project completion, thereby mitigating the risk of prolonged nuisance. These strategies were based on two major principles: the use of 3D and 4D BIM tools to reduce errors, and the shifting of the activities, which depended on land expropriation, out of the critical path.

BIM scenarios and their benefits

List of BIM scenarios implemented during the tender phase:

- Data exchange with other project partners/ project disciplines
- Generating quantities from the 3D model
- Coupling of a 3D model to a planning (4D modeling)
- Cost estimation with the 3D model (5D modeling)

Overall, Prime contractor A had a highly intensive 4D BIM implementation during the procurement phase. The use of 4D BIM tools largely supported Prime contractor A in developing its risk mitigation strategies. First, Prime contractor A used Synchro Pro to support the development of the core strategy. Four variants of the design for the outer gate head, anchor pilings, and temporary foundations were modelled. Various sequences of constructing and demolishing the temporary foundations and anchor pilings were loaded in Synchro Pro. The resulting 4D models provided a visualization of the objects to be constructed and their sequence of construction, through which the prime contractor's tender team could navigate in various time periods and in various arbitrary viewpoints. In an iterative process supported by the 4D BIM tool, the tender team could explore which combinations of the design variants and construction/demolition sequences would keep the middle lock operational for the longest period. Following this process, it was possible to keep the middle lock operational for four out of the five years of the construction duration.

Second, Prime contractor A also used Synchro Pro to check the completeness of the 3D model and the construction schedule. Activities as well as objects that were not linked to any object and any activity, respectively, were identified by the BIM manager, who then notified either the planner or the designer. This increased the robustness of the schedule, which mitigated the risk of delay to project completion, and consequently, the risk of prolonged nuisance.

Last, the use of the 4D BIM tool allowed for efficient testing of the feasibility of the strategies. Prime contractor A could visually inspect the 4D model for design and workflow clashes, as well as task dependencies. Using the clash detection functionality of Synchro Pro, Prime contractor A could also automatically check for clashes in the design, while considering the temporal aspect. An additional benefit of using 4D BIM tools for testing the feasibility and constructability was a lower tender price. By testing the feasibility of the risk mitigation strategies and the major construction strategies, Prime contractor A was ensured of the soundness of its tender, and was able to reduce its risk profile.

The result was a highly effective overall strategy for mitigating the risk of nuisance. The client evaluated the risk mitigation strategies proposed by Prime contractor A and assigned the overall plan with an outstanding added value. Most effective strategies cited by the client were to keep the middle lock operational for four years out of five years of construction duration, and to minimize the use of canal locks and waterways for construction purposes.

F.1.3. Prime contractor B

Prime contractor B defined nuisance as unsafe conditions, uncomfortable situations, and increased passage time. Unsafe conditions are expressed in (almost) accidents, and can be avoided by following safety rules and regulations. Uncomfortable situations, such as inadequate waiting places and unfamiliar situations, do not lead to increased passage times or unsafe conditions, but make it more difficult or less enjoyable for the users of the canal lock to make use of the facility. Increased passage time is caused by a reduction in the capacity of the locks facility, which can be caused by the unavailability of the middle lock as a result of construction works, by the use of the canal locks for construction purposes, and by the obstruction of the waterways by construction related activities.

Based on the risk analysis conducted by Prime contractor B, unavailability of the middle lock for locking would not increase passage time, since the east and west locks had adequate capacity to absorb the shipping traffic serviced by the middle lock. Instead, the risks to nuisance considered by Prime contractor B were the use of the canal locks for construction purposes, and the obstruction of the waterways by construction related activities.

Accordingly, Prime contractor B developed risk mitigation strategies aimed at preventing the use of the canal locks by construction-related ships; separating the work space and public space; creating ample waiting place; and effectively communicating with the users of the canal locks.

Prime contractor B also developed strategies for mitigating the risk of delay to project completion. One of these strategies was related to construction sequencing. Prime contractor B divided the concrete pouring for the lock chamber into two separate streams that could be conducted in parallel, to accelerate the execution of the activity. As a result, a buffer in the concrete schedule was created, which could absorb a delay in preceding activities.

BIM scenarios and their benefits

List of BIM scenarios implemented during the tender phase

- Data exchange with other project partners/ project disciplines
- Generating quantities from the 3D model
- Coupling of a 3D model to a planning (4D modeling)
- Cost estimation with the 3D model (5D modeling)

The use of a 4D BIM tool slightly supported the development of the above risk mitigation strategy. Prime contractor B developed the 3D model to the same level of detail as the number of planned concrete pouring activities. Then, Prime contractor B used Autodesk Navisworks to visualize various pouring sequences and identify which pouring sequence would result to least distance travelled by the trucks. This resulted to an optimum concrete pouring sequence, with the shortest distance travelled by the trucks, and consequently, the fastest pouring sequence.

Prime contractor B also used Autodesk Navisworks to test the availability of the waiting places. By modeling the temporary facilities necessary for the waiting places and linking them to the construction schedule, Prime contractor B could visually inspect if the prerequisite activities needed to create the waiting places at various locations were executed at the correct moments. In this way, Prime contractor B could ensure that the planned waiting places for each construction phase would be available as proposed in the risk mitigation strategy.

Bottlenecks

The client evaluated the risk mitigation strategies proposed by Prime contractor B to have minimum effect on the risk of nuisance and assigned them a minimal added value. The client found that there remained considerable risks related to nuisance that were not mitigated by Prime contractor B. The construction method chosen by Prime contractor B would lead to a significant reduction of the capacity of the locks facility because the middle lock is inoperable for most of the construction duration. At the same time, the risk mitigation strategies proposed by Prime contractor B did not address this reduced capacity. This combination would leave the users of the canal locks facility vulnerable to increased passage times, long waiting times, unsafe conditions, and economic losses if one of the two remaining canal locks becomes inoperable because of foreseen and unforeseen circumstances.

Barriers to implementing BIM

Overall, Prime contractor B had a low 4D BIM implementation during the procurement phase. Aside from the examples given above, Prime contractor B did not use 4D BIM tools for other purposes. The prime contractor cited three main reasons for this. First, the dynamic nature of the procurement phase made it difficult to link the 3D model with the schedule. Many product and process decisions were made later in the procurement process. In addition, significant changes to the planning, such as the shifting of construction phases to align them with cash flow moments, were made a couple of weeks before the deadline of the tender. A change in the schedule could require a total remodeling of the 3D object to achieve the same level of detail. In addition, since the 4D model required a schedule as an input, Prime contractor B could only develop a concise 4D model much later in the procurement process, under high time pressures.

Second, Prime contractor B did not perceive the usefulness of 4D BIM tools in developing its risk mitigation strategies. The main objective of Prime contractor B for developing a 4D model was to comply with the client's requirements. Prime contractor B expressed that if the client had not demanded the submission of a 4D model, then it would not have developed a 4D model during the procurement phase. 4D modeling would be more valuable for Prime contractor B during the project engineering and construction phase, when most design and process decisions have been made, and the schedule has been developed in more detail.

Last, the way the 3D models were developed did not align with the requirements for creating the 4D model. Prime contractor B developed the 3D models mainly for engineering and cost estimation purposes. According to the BIM manager, this made it difficult to link the objects with the activities. The 3D models often had a different level of detail from the schedule. In addition, linking the 3D objects to the corresponding activities in the schedule was time consuming and often difficult.

F.1.4. Prime contractor C

Prime contractor C identified two factors that determine nuisance for the users: the increase in passage time through the canal locks facility as a result of construction activities; and unexpected situations. Consequently, Prime contractor C proposed risk mitigation strategies aimed at mitigating the two factors: preventing and minimizing the increase in passage time, and guaranteeing predictable and reliable waterway layout and communication. The development of these strategies required accounting for site space utilization and logistics for the movement of materials during the planning process. The design of the new lock was not influenced by these strategies.

To prevent and minimize the increase in passage time resulting from construction activities, Prime contractor C proposed to keep the middle lock operational for two out of the five years of the construction duration. This was achieved by shifting the construction activities taking place around the middle lock later in the construction phase to keep the waterways leading to the middle lock accessible. In addition to this strategy, Prime contractor C proposed to transport most of its materials in and out of the construction site without the use of the canal locks. The remaining materials that have to be transported via the locks will be transported outside the rush hours.

The second theme is concerned with guaranteeing predictable and reliable waterway layout and communication to the users. The strategy for predictable and reliable waterway layout was to have maximum four temporary waterway layouts throughout the construction phase. This required planning the site space utilization throughout the construction phase.

Prime contractor C also developed strategies to mitigate the risk of delay to project completion. These strategies involved creating buffers in the planning for activities dependent on land expropriation, to mitigate the risk of delay when land is not acquired by the client on time. Other strategies focused on reducing errors in the design and on shifting the testing of installations earlier in the construction process, to mitigate the risk of failure during the construction phase.

Another strategy involved the realignment of data cables. Prime contractor C planned to realign one of the existing data cables, which was at its maximum length, without extending the length of the cable. If the new alignment was longer than the existing alignment, then the prime contractor would have to extend the length of the data cable, which would take much longer and increase the risk of damage and delay.

Therefore, Prime contractor C had to define a new alignment that was the same length or shorter than the existing alignment.

BIM scenarios and their benefits

List of BIM scenarios implemented during the tender phase

- Data exchange with other project partners/ project disciplines
- Generating quantities from the 3D model
- Coupling of a 3D model to a planning (4D modeling)
- Cost estimation with the 3D model (5D modeling)

Overall, Prime contractor C had a moderately intensive 4D BIM implementation during the procurement phase. Prime contractor C used Autodesk Navisworks to identify an available space for realigning the data cable at a specific moment in the construction phase. Then, Prime contractor C used a 3D modeling tool to model the space required for the data cable, measure the new alignment, and then adjust the alignment if the length was too long. Using the 3D modeling tool, instead of a 2D drawing, really supported this iterative process because it could accurately measure the length of the new alignment by taking its depth into account. Prime contractor C also used Autodesk Navisworks to plan site space utilization throughout the construction phase. The prime contractor used the 4D visualization of the integrated 3D models of all design disciplines and the construction schedule during the tender team meetings. By visualizing and navigating through the 4D model at any given time period and at various viewpoints, the tender team could identify spaces in the site that were available at that given period or could be optimized. With the support of the 4D BIM tool, Prime contractor C could guarantee the integrity of the design and develop an optimum site space utilization.

The use of the 4D BIM tool also efficiently supported the testing of the strategies in relation to safety. Using the walkthrough tool of Autodesk Navisworks in the 4D model that was already developed for other purposes, Prime contractor C could simulate what the skippers could see and evaluate the scene in relation to sight lines and safety. In this way, the feasibility of the strategies with regards to safety could be efficiently tested with the support of the 4D BIM tool.

Bottlenecks

The client evaluated the risk mitigation strategies proposed by Prime contractor C as moderately effective and assigned them a reasonable added value. The strategies to prevent the use of the canal locks for construction purposes effectively mitigated the risk of nuisance. The strategy to keep the middle lock operational for two out of the five years of the construction duration also effectively mitigated the risk of nuisance. However, the client found the proposed period of two years inadequate to significantly lower the risk.

Barriers to implementing BIM

One of the challenges faced by Prime contractor C in using the 4D BIM tool during the procurement phase was due to the dynamic nature of the procurement process, which was similar to the experience of Prime contractor B. In addition, the 4D model requirements specified by the client influenced Prime contractor C in its development of the 4D model. Prime contractor C expressed that a lot of time was spent on fulfilling the client's 4D model requirements. Meanwhile, the resulting 4D model did not have much added value for the prime contractor. Another challenge faced by Prime contractor C was related to the tool itself. The soil model developed by Prime contractor C distinguished the different layers of soil for each 100 cm^2 of land. This information is necessary to plan the import and export of soil for each construction phase in a manner that would cause the least nuisance. However, the size of the soil model was too large and dense to use in Autodesk Navisworks. Therefore, Prime contractor C could not use the 4D model to automatically extract the quantities of soil for each construction phase.

Appendix G. 4D modelleringsplan NST

G.1.1. Doelstelling

NST streeft m.b.t. het gebruik van 4D modellering (4DM) de navolgende doelen na:

- Het via 4DM als communicatiemiddel, inzichtelijk en daardoor bespreekbaar maken van de tot stand te komen ontwerp- en de bouwfasering van NST.
- Gebruik 4DM ter validatie van het ingediende bouwfaseringsplan.

G.1.2. Eisen aan het 4D-modelleringsplan

Het 4D-modelleringsplan dient ten minste:

1) Te bestaan uit digitale bestanden conform de volgende specificaties:
    a. Te viewen en in te lezen op zowel geometrische als niet geometrische data;
    b. Bestandsformat: een Industrial Foundation Classes (IFC)-file;
    c. Voor iedere object(instantie) geldt een unieke objectcode (identificatie), de identifier van het moederobject en een NEN-code + eventueel andere code t.b.v. andere decompositiestructuur. Hiermee wordt een decompositiecodering bedoeld. Aanbesteder wenst een logische opbouw in de structuur van het model.
    d. Gerelateerd te zijn aan het Rijksdriehoeksstelsel (RD) en bij het 4D modelleren dienen coördinaten actief te worden ingesteld.
2) te voldoen aan de Aanbestedingsdocumentatie;
3) consistent te zijn met alle onderdelen van de inschrijving;
4) het bouwfaseringplan te onderbouwen met inzicht in de kritische onderdelen, eventuele hulpconstructies;

G.1.3. Proces voor het 4D-modelleringsplan tijdens de dialoog

Met betrekking tot het onderwerp 4DM, zal aanbesteder per gegadigde één of meer specialistische overleggen inplannen. Gegadigde dient met betrekking tot 4DM NST, een plan 4DM op te stellen. Dit plan 4DM dient in stappen aangeleverd te worden voor behandeling in de specialistische overleggen. Gegadigde dient tijdens de dialoogfase hun ontwerp in 4D uit te werken, dit ontwerp te bespreken (met de applicatie van de gegadigde zelf) tijdens de dialooggesprekken en uiteindelijk aan te leveren bij inschrijving. Tijdens de tweede dialoogfase zal de uitwerking van het ontwerp en bouwfasering middels een 4D model aantoonbaar en bespreekbaar gemaakt dienen te worden door de gegadigde. Hiervoor dienen zij een aanpak te presenteren waarin de diepgang, afstemming, werkwijze en de relatie met de dialoogresultaten inzichtelijk gemaakt worden.

G.1.4. Uitwerking

De gegadigden dienen het totale 3D-ontwerp minimaal op het ontwerp LOD (level of development*) 200 uit te werken, hierbij dienen minimaal de volgende 3 kritische delen nader uitgewerkt te worden in LOD 300: sluisdeur, brug en terrein(inrichting).

G.1.5. Toetsaspecten

Doel: Inzicht in uitvoerbaarheid activiteiten en daarbij minimale hinder veroorzaken tijdens B&O fase

1) Brug
    a. Toegankelijkheid (bijv. op eenvoudige manier vervanging en opslag van de cilinders);
    b. Profiel vrije ruimte bij in conserveren en inspecteren van de brug (beschikbaarheid van laagwerker);
    c. Ruimtelijke kwaliteit en vormgeving gekoppeld aan RKV-plan.
2) Sluisdeur
    a. Toegankelijkheid (bijv. op eenvoudige manier vervanging en opslag van de boven- en onderrolwagen);
    b. Profiel vrije ruimte bij in situ conserveren en inspecteren (van buitenzijde en binnenzijde) van de deur;
    c. Ontwerp en B&O van middenstandsgeleiding.
3) Terrein(inrichting van de Nieuwe Sluis)
    a. Ruimtebeslag (ruimte voor aannemers) en koppeling met het esthetisch programma van eisen opstelplaatsen kranen, kabellopen, nivelleerschuiven, riool, kelders, putten, groenvoorzieningen, wegen, hekwerken, veiligheidszones, serviceweg over de deur;
    b. Integraliteit, bijvoorbeeld tijdens onderhoud niet hinderen logistieke werkzaamheden;
    c. Ontsluiting (aansluiting doorgaande wegen, toegangsvoorzieningen);
    d. Brandblusvoorziening (pompkelder, energievoorziening, aansluitpunten FIFI).

G.1.6. Uitwerking

De gegadigden dienen ten behoeve van minder hinder een 4D-modellering uit te werken waarin het principe van het integraal ontwerpen en plannen van het globale ontwerp wordt aangetoond. Specifiek betekent dit het 3D-model van het sluizencomplex op LOD 200 (level of development*) gekoppeld aan de balkenplanning van het project. Dit dient door de aanbesteder met een, in de markt, vrij toegankelijke viewer bekeken te kunnen worden. De 4D-modellering dient inhoudelijk overeen te komen met de 10 (2D) bouwfaseringstekeningen conform het gestelde in dit inschrijvings- en beoordelingsdocument.

G.1.7. Toetsaspecten

Doel: Inzicht in (integrale) uitvoeringsfasering en bouwlogistiek in relatie tot hinder voor scheepvaart en wegverkeer

1) Uitvoeringsfasering
    a. Gehele projectgebied en omliggende infrastructuur (water en weg);
    b. Subsystemen en objecten met relaties tot hinder (verwijderen, aanbrengen en handhaven);
    c. Tijdelijke objecten (verwijderen en aanbrengen);
    d. Handhaven functies scheepvaart, wegverkeer, spuien en waterkering (locaties en routes);
    e. Gekoppeld aan balkenplanning;
2) Bouwlogistiek
    a. Bouwstromen via water en weg (type en route);
    b. Grondstromen via water, weg, persleiding e.d. (type en route);
    c. Bouwwegen;
    d. Kruisingen bouwwegen met wegen;
    e. Overslagpunten en werkhavens;
    f. Werkterreinen;
    g. Bouwkuipen;
    h. Zones met kraaninzet;
    i. Betoncentrale (indien van toepassing);
    j. Depots;
    k. Gekoppeld aan balkenplanning.

G.1.8. Beoordeling van het plan 4DM

Aanbesteder heeft een beoordelingscommissie ingesteld, die controleert of het door gegadigde geleverde plan 4DM aan de eisen voldoet. De bevindingen worden als advies aan aanbesteder verstrekt.

G.1.9. Voortbouwen op het plan 4DM

Gegadigde is gehouden om bij de uitwerking van de opdracht voort te bouwen op ingediende 4DM en het bovenvermeld advies.

Appendix H. Aanbevelingen m.b.t. 4D BIM n.a.v. de casestudie NST

H.1.1. Management samenvatting

Uit recente onderzoek blijkt dat slimme bouwlogistiek in de praktijk loont (Van Merriënboer & Ludema, 2016). Door sneller, slimmer en duurzamer bouwen is er minder overlast voor de omgeving, minder luchtvervuiling en aanzienlijke besparingen voor de opdrachtnemer. Bij een casestudie in dit onderzoek werd zelfs gemeten dat slimme bouwlogistiek leidde tot 69% minder ritten naar de bouwplaats, 69% minder voertuig kilometers, 68% minder CO_2 uitstoot en 81 minuten besparing voor de leverancier per rit (Van Merriënboer & Ludema, 2016). Het is dus duidelijk dat bouwlogistiek een belangrijke rol heeft in de bereikbaarheid, leefbaarheid en veiligheid van de omgeving.

In de tender van de Nieuwe Sluis in Terneuzen is aan de gegadigden gevraagd om een 4D modelleringsplan in te dienen. Dit is voor zover bekend de eerste keer binnen Rijkswaterstaat. Voor de 3D/4D BIM uitvraag zijn eisen aan het 3D/4D model gesteld en zijn toetsaspecten geformuleerd. Uit de ervaring met het gebruik van 4D BIM in de casestudie NST blijkt dat dit tot aanzienlijke besparingen, minder CO_2 uitstoot en minder hinder voor de omgeving kan leiden.

Doelstelling van dit document is om de kennis en ervaringen met betrekking tot 4D BIM in relatie tot bouwlogistiek, die is opgedaan tijdens de tender van NST, vast te leggen zodat toekomstige projecten ervan kunnen leren. Wanneer aanbestedende diensten 4D BIM in het kader van minder hinder willen uitvragen kan dit document hun helpen in het opstellen van de eisen, toetsaspecten en EMVI-beoordelingscriteria met betrekking tot 4D BIM.

Het rapport is als volgt opgebouwd. Eerst wordt het onderzoekskader vastgelegd (Paragraaf H.1.2). Vervolgens wordt de evaluatie van de 4D BIM uitvraag in de tender van het project Nieuwe Sluis Terneuzen besproken (Paragraaf H.1.3). Hierna volgt de aanbevelingen met betrekking tot 4D BIM in de tender van toekomstige infrastructurele projecten (Paragraaf H.1.4). Als laatste worden de vervolgstappen voor verdere implementatie van 4D BIM aangegeven (Paragraaf H.1.5).

H.1.2. Onderzoekskader

Een tal van onderzoeken zijn het eens dat het delen van kennis en informatie cruciaal is voor een efficiënte bouwlogistiek. Informatie en Communicatie Technologie (ICT) ondersteunt en faciliteert het delen van kennis en informatie. Eén van de belangrijkste ICT's in de bouw op dit moment is BIM. Een 'Bouwwerk Informatie Model' is "een digitale representatie van hoe een bouwwerk is ontworpen, wordt gerealiseerd en/of daadwerkelijk is gebouwd" (Bouw Informatieraad, 2015). Hoe een bouwwerk wordt gerealiseerd wordt vaak getoond in een 4D BIM. 4D BIM betekent dat het model naast de 3D-geometrische informatie en niet-geometrische informatie, ook informatie gerelateerd aan het tijdsaspect bevat.

Uit vele casestudy blijkt dat het gebruik van 4D BIM leidde tot effectievere communicatie tussen alle betrokkenen in het bouwproces, beter beoordeling van alternatieve oplossingen en een toename in de toepassing van prefabricatie (Babič, Podbreznik, & Rebolj, 2010; olde Scholtenhuis, Hartmann, & Dorée, 2016; Post, 2012; Trebbe et al., 2015). De koppeling tussen 4D BIM en Big Data, zoals data vanuit GIS, verkeersmodellen en CO_2 rekentools, kan planners helpen tijdens de besluitvorming door de effecten van de geplande bouwactiviteiten op de omgeving en het milieu te integreren en te visualiseren (Irizarry et al., 2013; Jupp, 2017; Wong et al., 2013; Zanen et al., 2013). Dus, het gebruik van 4D BIM ondersteunt en faciliteert een slimme bouwlogistiek.

De reden om 4D BIM uit te vragen is om te sturen op slimme bouwlogistiek. Maar, hoe vraag je 4D BIM uit? Welke informatie heb je nodig? Onderzoek hierover is dus belangrijk. In samenwerking met Rijkswaterstaat en de Nederlandse Vereniging voor Inkoopmanagement (NEVI) doet de Universiteit Twente onderzoek op dit gebied. Het onderzoek wordt uitgevoerd in het kader van een tweejarige post-master, PDEng (Professional Doctorate in Engineering) opleiding.

Onderdeel van het PDEng opdracht is de casestudie Nieuwe Sluis Terneuzen (NST). In de tender van NST is zowel 3D als 4D BIM uitgevraagd. Dit is een uniek geval en een goede kans om de uitvraag van 4D BIM te onderzoeken. De casestudie is uitgevoerd met de nadruk op het 4D BIM aspect in relatie tot minder hinder.

De resultaten van de casestudie NST zijn in een drietal producten vastgelegd. Ten eerste is er een aanzet gemaakt voor een informatieleveringsspecificatie (ILS) ten aanzien van 4D BIM. De aanzet van een ILS 4D BIM bevat eisen ten behoeve van toe te passen bestandsformaten en standaarden, het leveringsproces, te leveren informatie en de kwaliteit van de informatie. Ten tweede zijn er aanbevelingen gedaan over hoe 4D BIM een onderdeel kan uitmaken van de inkoopstrategie tijdens een concurrentiegerichte dialoog. Ten derde wordt er een wetenschappelijke paper geschreven over de casestudie NST.

In de realisatie van de drietal producten vond nauwe samenwerking plaats met: het dialoogteam en de beoordelingscommissie 4DM van het project NST, RWS BIM programma, betrokken bouwpartners na gunning en de Universiteit Twente (zie Tabel **1** voor lijst van betrokkenen).

Tabel 1. Lijst van betrokkenen.

De 4DM beoordelingscommissie bestaat uit de volgende leden:
Marco Heijdens (dialoogsecretaris, NST) Koen de Winne (koppeling met dialoogteam, NST) Ada de Waard (adviseur informatievoorziening beheer en BIM, RWS) Andre Tieleman (adviseur projectomgeving, NST) Sjaak Michielsen (kennis beheer en onderhoud, NST) Jos de Dreu (CIV, RWS) Joris van Gool (adviseur BIM, RWS) Mark Moerman (adviseur BIM, Count&Cooper) Andreas Heutink (adviseur Innovatie en Markt, GPO RWS) Ruth Sloot (adviseur BIM en logistiek, Universiteit Twente)
De volgende leden van de tenderteams van de drie gegadigden (Sassevaart, Sas Ter Nessen en Alliantie Sluis Terneuzen) waren geïnterviewd in het kader van dit onderzoek:
Plannings- en faseringsmanagers BIM managers Tendermanagers
In de realisatie van de producten van dit onderzoek vond nauwe samenwerking plaats met de volgende:
Marco Heijdens (dialoogsecretaris, NST) Martijn Arkesteijn (BIM programma, CIV RWS) Hans Voordijk (universitaire hoofddocent, Universiteit Twente)

H.1.3. Casestudie Nieuwe Sluis Terneuzen

In het kader van de casestudie NST is de 4D BIM uitvraag in kaart gebracht en geëvalueerd. Dit is gedaan door middel van een documentenanalyse, het bijwonen van specialistische overleggen tijdens de concurrentiegerichte dialoog en, na de gunning, het interviewen van de drie gegadigden. Daarna is een deskresearch uitgevoerd om te kijken naar aanbevelingen ten behoeve van het uitvragen van 4D BIM vanuit de literatuur. Op basis van de evaluatie van de 4D BIM uitvraag in Nieuwe Sluis Terneuzen en de resultaten van de deskresearch zijn aanbevelingen gedaan op de wijze waarop 4D BIM kan worden uitgevraagd bij toekomstige projecten.

Project beschrijving
De Nieuwe Sluis Terneuzen (NST) is aanbesteed middels een concurrentiegerichte dialoog. Na de eerste dialoogfase vond er trechtering plaats naar drie gegadigden: Alliantie Sluis Terneuzen (AST), Sas Ter Nessen (STN) en Sassevaart (SSV).

De winnende aanbieding is gekozen middels de EMVI met de beste prijs-kwaliteitverhouding. De kwalitatieve EMVI-criterium 'risicobeheersplan' bestaat uit zeven sub-criteria (zie onder Tabel **2**).

Tabel 2. Kwalitatieve EMVI-criteria met de bijbehorende kwaliteitswaarden.

Kwalitatieve EMVI-criteria		Max. te behalen fictieve kwaliteitswaarde
1	Bodemopbouw in relatie tot ontwerp- en uitvoering	10
2	Schade aan het sluizencomplex en de omgeving	40
3	Het risico op niet behalen van de opleveringsdatum	30
4	Het risico op hinder scheepvaart	25
5	Risico kwaliteitsbeheersing	25
6	Projectdoelstellingsrisico industriële automatisering	25
7	Life Cycle Costs	40

Logistieke kwaliteit maakte geen onderdeel van de EMVI. Deze was echter wel van belang in het project, gezien dat de aanbesteder het belangrijk vond dat het project gerealiseerd wordt op een snelle manier en met minder hinder voor de omgeving. Deze belangen waren uitgedrukt in de EMVI-criteria 3 en 4. Doelstellingen van de aanbesteder in relatie tot EMVI-criteria 3 en 4 zijn:

1) Het mitigeren van het risico dat de vooropgestelde opleveringsdatum niet gehaald wordt.

2) Het verder verlagen van de hinder die optreedt voor de scheepvaart op en rondom het sluizencomplex ten opzichte van de contractuele eisen.

In dit project was de koppeling tussen de logistieke kwaliteit en de 4D BIM uitvraag niet gemaakt. 4D BIM was als een aanvullend product uitgevraagd. In de volgende paragraaf wordt het proces van opstellen van de 4D BIM uitvraag en de resulterende 4D BIM uitvraag besproken.

4D BIM uitvraag in de concurrentiegerichte dialoog
In de tender van NST is 3D en 4D BIM uitgevraagd. Aanleiding van de uitvraag bij NST was om inzicht te krijgen tot de RAMS aspecten vanuit het 3D model. De 3D BIM uitvraag was dan uitgegroeid tot zowel 3D als 4D BIM. In de volgende paragrafen wordt de focus gelegd op de 4D BIM uitvraag in relatie tot minder hinder.

Doelstelling voor het uitvragen van 4D BIM bij NST was om het 4D model te gebruiken als afstem- en communicatiemiddel tussen aanbesteder en gegadigden over het ontwerp en bouwfasering tijdens de dialooggesprekken maar ook ter validatie van deelproducten voor de EMVI-beoordeling. Hiervoor heeft de aanbesteder de gegadigden gevraagd om een 4D modelleringsplan (4DM) in te dienen. In de bijlage M (Informatieleveringsspecificatie) van de Vraag Specificatie Proces (VSP) staat beschreven:

"Tijdens de 2e dialoogfase zal de uitwerking van het ontwerp en bouwfasering middels een 4D model aantoonbaar en bespreekbaar gemaakt dienen te worden door de Gegadigde. Hiervoor dienen zij ten tijde van de 3e dialoogronde (01-05 december 2016) een aanpak te presenteren waarin de diepgang, afstemming, werkwijze en relatie met de dialoogproducten inzichtelijk gemaakt worden.

Bij inschrijving dienen de finale bestanden aangeleverd te worden conform de volgende specificatie:

- Te viewen en in te lezen op zowel geometrisch als niet geometrische data.
- Bestandsformat: een Industrial Foundation Classes (IFC)-file (softwarepakket onafhankelijk)."

In november 2016 heeft de aanbesteder een 4DM beoordelingscommissie ingesteld om de aanbesteder te ondersteunen over de 4D BIM uitvraag (zie Bijlage B voor de leden van de 4DM beoordelingscommissie). De 4DM beoordelingscommissie adviseerde het dialoogteam van de aanbesteder over de formulering van de 4D BIM uitvraag.

Een van de vragen was of het 4DM plan als een geldigheidsproduct wordt uitgevraagd of alleen als VSP. Door juridische redenen was het besloten om de 3D en 4D modellen niet als geldigheidsproducten uit te vragen. De aanbesteder besloot ook om geen koppeling te maken tussen het 4DM plan en de 7 EMVI's. In plaats daarvan is er voor gekozen om de uitvraag te beperken tot kritische delen van het ontwerp en de bouwfasering, mede omdat er onvoldoende tijd was binnen de tenderfase om de koppeling goed te definiëren.

Een andere belangrijke discussie was de definitie van LOD. LOD staat voor zowel Level of Development als Level of Detail. Beide definities zeggen iets over de mate van detail (hoe hoger het detailniveau, hoe gedetailleerder het model), maar alleen Level of Development zegt iets over de betrouwbaarheid van de afmetingen, locatie en oriëntatie van een objectinstantie. In dit project was het besloten om de definitie Level of Development te hanteren, zoals beschreven in 'Level of Development Specification', een internationaal gedragen definitie gemaakt door BIMforum (BIMforum, 2016). Maar welke LOD-niveau vraag je uit? De aanbesteder wil graag middels het 4DM verifiëren dat haar risico's afgevangen worden in de gekozen bouwmethodiek/ ontwerp. De aanbesteder wenst overtuigd te worden dat de gegadigden in de tenderfase de juiste (kritische) aspecten in het vizier hebben en dus na gunning de juiste zaken oppakken. Daarnaast moet de aanbesteder rekening houden met wat mogelijk is voor de gegadigden. Het was besloten om verschillende LOD-niveaus te specificeren omdat er verschillende LOD-niveaus voor verschillende doelen nodig zijn. Het totale 3D model dient in LOD-200 uitgewerkt te worden. Hierbij dienen kritische onderdelen in LOD-300 uitgewerkt te worden. Het 4D model dient in LOD 200 uitgewerkt te worden.

De resulterende 4D BIM uitvraag zoals beschreven in het Inschrijvings- en Beoordelingsdocument (I&B) versie B is toegevoegd als bijlage (Appendix G). Na het verstreken van de 4D BIM uitvraag was er een extra specialistisch overleg waarin de gegadigden hun aanpak, de stand van zaken en zijn doelstellingen, verwachtingen en aandachtspunten met betrekking tot 4D BIM met de 4DM beoordelingscommissie hebben gedeeld. Tabel **3** geeft de gestelde aandachtspunten en vragen met de bijbehorende antwoorden weer.

Voor de leden van de 4DM beoordelingscommissie was het nog onduidelijk wat zij precies moeten beoordelen en hoe deze beoordeling/advies wordt meegenomen in de totale beoordeling van de inschrijvingen. Besloten werd om na de dialoogfase een wrap-up sessie te houden, waarin teruggekeken wordt op de toepassing van het 4DM plan van elke gegadigde.

Het doel van de wrap-up sessie was voor de gegadigden om invulling te geven over de 4D BIM uitvraag door een toelichting op drie onderdelen te geven: 1) de 4DM organisatie en werkwijze tijdens de tender, 2) het gebruik van de 3D en 4D modellen op minimaal vier toetsaspecten genoemd in het I&B en 3) de toepassing van 4D BIM na gunning.

Aan het einde van hun toelichting verwachte de gegadigden een beoordeling van de 4DM beoordelingscommissie. De gegadigden wilden graag weten en een schriftelijk mededeling krijgen of zij aan de 4D BIM uitvraag hebben voldaan. Een zorg van de gegadigden was dat hun inschrijvingen ongeldig worden verklaard aan de hand van hun 4D model. Om hun zorg weg te nemen heeft de 4DM beoordelingscommissie aangegeven dat zij aan de 4D BIM uitvraag hebben voldaan en dat de beoordeling van het 4DM plan als advies wordt verstrekt aan de aanbesteder.

Naast de wrap-up sessie zijn aan de gegadigden gevraagd een 4DM plan in te dienen. Hiervoor heeft de aanbesteder een concept 4DM plan opgesteld welke door de gegadigden moet worden gebruikt. Dit plan bevat de volgende 4 onderdelen:

1) Inzicht in aanpak 3D en 4D modellering na gunning
2) Voorbeelden van toepassing 3D en 4D modellering
3) Beknopte handleiding en specificatie van de aangeleverde modellen
4) Visie op de interactie en samenwerking Opdrachtgever (OG) en Opdrachtnemer (ON) met betrekking tot informatiemanagement.

De ingediende 4DM plannen zijn na de tender door controleteams getoetst. De ingediende 4D modellen waren getoetst ten aanzien van consistentie met bouwfasering. Daarna heeft de beoordelingscommissie de ingediende 4DM plannen en modellen gekregen. In de beoordelingscommissie ontbrak echter wel de tijd om de modellen te gebruiken en zijn daarom niet gebruikt.

Tabel 3. Aandachtspunten en vragen met betrekking tot de 4D BIM uitvraag.

Vraag/Aandachtspunt	Antwoord
LOD-300 is niet haalbaar tijdens de tenderfase. Wat is de achtergrond van LOD-300? Geld dit voor alle onderdelen (bijv. ladders, bolders, leuningen, e.d.)? Daarnaast is een LOD-300 voor de terreininrichting te hoog voor in de tenderfase.	Redenatie is van risico's en functionaliteit. LOD-300 betekent betrouwbaar in hoeveelheid, afmeting, vorm, locatie en oriëntatie. Objecten die volgens gegadigde behoren tot de kritische aspecten van het project dienen op LOD-300 te worden uitgewerkt. Overige onderdelen mogen op een lager detailniveau te worden uitgewerkt.
Wat is de verwachting van de aanbesteder over het detailniveau van het 4D model? Bijv. wenst de aanbesteder iedere betonstort gevisualiseerd in het model te zien? Het gevraagde LOD-niveau is te hoog omdat een hoge detail van de planning wordt vaak niet bereikt tijdens de tender.	De verwachting van de aanbesteder is dat het 4D model de kritische aspecten van het project in beeld brengt en overtuigt raakt dat de gegadigde in staat is om het plan succesvol te realiseren. De detaillering wordt mede bepaalt op basis van de risico inschatting van de gegadigde.
Een IFC bestandformat is niet geschikt voor infrastructurele objecten (zoals wegen, terreinen, grondwerk, e.d.) en 4D modellen. Het omzetten naar IFC zou leiden tot veel informatieverlies. Zijn andere open formaten ook toegestaan als uitwisselingsformaat?	Het model dient door de aanbesteder met een, in de markt, vrij toegankelijk viewer bekeken te kunnen worden. De online viewers zullen moeten worden gespecificeerd om hier uitsluitsel over te geven.
De aanbesteder wenst om de verkeersrichtingen en –intensiteiten per bouwfase in het model te zien. Dit zijn praktisch onhaalbaar te modelleren. Daarnaast geeft één van de gegadigden dat het maken van een 4D model tijdens de tenderfase geen meerwaarde heeft voor gegadigde zelf en is meer als extra werk.	De aanbesteder wil de gegadigden niet opzadelen met extra werk. Aanbesteder geeft aan dat het niet de bedoeling is om mooie visualisaties te zien waarvan niet duidelijk wordt waar de knelpunten liggen en waar/wanneer beheersmaatregelen zijn getroffen. Het gaat in de tender meer over duiding dan over detaillering. De doelstelling t.a.v. communicatie is leidend.

Evaluatie van de 4D BIM uitvraag na de tender NST

In deze paragraaf wordt de 4D BIM uitvraag geëvalueerd. Hier wordt gekeken naar de positieve punten en de verbeterpunten. De evaluatie is gemaakt op basis van gesprekken met het dialoogteam NST en interviews met de drie gegadigden.

Alle drie gegadigden zijn van mening dat 3D modelleren zeker waardevol is tijdens de tenderfase. Door het maken en gebruiken van 3D modellering kunnen zij de integraliteit van het ontwerp waarborgen. Bovendien gebruiken zij het 3D model om hoeveelheden te genereren ten behoeve van kostencalculatie en planning. Bij grote integrale projecten, waar multidisciplinair gewerkt wordt, is BIM altijd vertegenwoordigd in het team.

Twee van de drie gegadigden hebben aangegeven dat het gebruik van 4D BIM tijdens de tenderfase meerwaarde voor hun hebben gehad. Zij geven aan dat de inspanning die zij hebben geleverd ten behoeve van de 4D BIM uitvraag niet veel meer was geweest als 4D BIM niet door de aanbesteder was uitgevraagd, alleen de focus van de inspanning was wel anders geweest. De gegadigden gebruikte het 4D model om detailoplossingen uit te werken en niet per se om hun bouwfaseringen te optimaliseren. Beide bouwconsortia passen 4D BIM ook toe in de tender van andere projecten. De meerwaarde van 4D BIM zit in de integratie van verschillende disciplines en de mogelijkheid om in het model op verschillende perspectieven en op verschillende bouwfasen te kunnen navigeren en visualiseren. Hierdoor krijgen de leden van het tender- of projectteam dezelfde instelling en kunnen ze de situatie beter begrijpen.

Voor eén van de drie gegadigden heeft het gebruik van 4D BIM tijdens de tenderfase bijgedragen aan aanzienlijke vermindering van hinder op de scheepvaart. Het 4D model heeft geholpen met het bedenken van de volgordelijkheid van de funderingen, wanneer ankers weg genomen kunnen worden omdat het sluisplateau gemaakt is en wanneer de ankers moeten blijven omdat de doorvaart kanaal daar nog zit. In een iteratief proces met behulp van het 4D model was de gegadigde naar de beste oplossing gekomen waarmee de Middensluis zo lang mogelijk open gehouden kon worden.

Er zijn ook punten voor verbetering. Zowel in het I&B als tijdens de specialistische overleggen was het duidelijk aangegeven dat het 4DM plan niet formeel beoordeeld zou worden door de beoordelingscommissie, maar wel als contractstuk dient. Ondanks de vele inspanningen van de gegadigden heeft de 4DM plannen niet bijgedragen aan de beoordeling van de inschrijvingen. Eén van de gegadigden moest zelfs vijf fte’s tijdens de laatste anderhalve maanden inzetten om aan de uitvraag te voldoen. Voor desbetreffende gegadigde heeft 4D BIM geen meerwaarde gehad tijdens de tenderfase.

Als de aanbesteder er voor had gekozen om de 4DM plannen mee te nemen in de beoordeling, dan had de aanbesteder veel inspanningen moeten leveren om informatie uit de aangeleverde 4D modellen te halen. De aanbesteder kon zelf in het 4D model navigeren en elementen aan- en uitzetten. De aanbesteder moest dus zelf bepalen welke elementen aan en uit te zetten en op welke invalshoek het model te bekijken. Het kan dus enige tijd kosten om de aangeleverde 4D modellen te begrijpen en om de juiste elementen aan en uit te zetten en de juiste invalshoek te gebruiken om de juiste informatie uit het 4D model te halen.

Tegelijkertijd is het niet aanbevolen om de 3D en 4D modellen als geldigheidsproducten uit te vragen. De modellen zijn opgesteld o.b.v. een ontwerpvisie met een bandbreedte van soms 20% - 30%. In een tender kan dit bandbreedte makkelijk 50% zijn, zeker op staal hoeveelheden. Als geldigheidsproduct is het model dus geldig binnen een bepaalde bandbreedte. De bandbreedte van het model moet dus bekend worden, alleen is het moeilijk om de bandbreedte van een model te bepalen want het verschilt per element. Daarnaast bestaat er geen standaarden om dit te bepalen.

De gegadigden hebben geen duidelijke richtlijnen gekregen waarmee zij kunnen bepalen of zij aan de uitvraag hebben voldaan of dat ze nog meer inspanningen moeten leveren. De eisen in het I&B verschilt met de uitleg die de gegadigden hebben gekregen tijdens de dialoog en het I&B was hiervoor verder niet aangepast. Een voorbeeld hiervan is dat andere bestandsformaten (behalve IFC) zijn ook toegestaan. Het was voor de gegadigden onduidelijk hoe het 4DM plan wordt beoordeeld en hoe deze beoordeling wordt meegenomen in de totale beoordeling van hun inschrijving. Het was dus ook onduidelijk voor de gegadigden of hun inschrijving ongeldig kon worden verklaard wegens het 4DM plan, wat zorgde voor veel onrust bij de gegadigden.

Ten slotte zijn de doelstellingen van de aanbesteder met betrekking tot 4D BIM niet volledig gehaald. De eerste doelstelling: “Het via 4DM als communicatiemiddel, inzichtelijk en daardoor bespreekbaar maken van de tot stand te komen ontwerp- en bouwfasering van NST”, was in lagere mate behaald dan de aanbesteder in het begin had verwacht. De 3D modellen waren wel gebruikt tijdens het ontwerpatelier in de tweede dialoogfase. De 4D modellen waren echter niet gebruikt als communicatiemiddel tijdens het specialistisch overleg met betrekking tot uitvoeringsfasering en bouwlogistiek. De gegadigden hebben hun 4D modellen wel vertoond tijdens het overleg, maar dat was alleen om de stand van zaken te laten zien en niet voor het bespreken van de tot stand te komen bouwfasering.

Ongeacht de bovengenoemde onvolkomenheden vonden alle drie gegadigden het positief dat BIM was uitgevraagd, alhoewel werd het begrip “BIM” in de uitvraag vermeden (in het I&B werd de termen BIM en model niet genoemd). De gegadigden vonden het positief dat ze op basis van kwaliteit waren beoordeeld. Daarnaast vonden de gegadigden het positief dat de aanbesteder de markt stimuleert om te innoveren door BIM uit te vragen.

H.1.4. Aanbevelingen

In de voorgaande paragrafen is de 4D BIM uitvraag in de tender van NST vastgelegd en geëvalueerd. In dit hoofdstuk worden aanbevelingen gedaan met betrekking tot het uitvragen van 4D BIM naar aanleiding van de casestudie NST.

Wanneer aanbesteders 4D BIM willen uitvragen is het van groot belang om voldoende kennis over (4D) BIM binnen de organisatie aanwezig te hebben. Kennis over (4D) BIM is belangrijk om vorm te kunnen geven aan de uitvraag, advies aan de gegadigden te kunnen voorzien en de insteek van de gegadigden op modelleringsaspecten te kunnen toetsen.

Voordat de aanbesteder 4D BIM gaat uitvragen, wordt de aanbesteder aanbevolen om een marktconsultatie uit te voeren. Uit de marktconsultatie krijgt de aanbesteder te weten wat de markt kan bieden met betrekking tot 4D BIM. Op basis hiervan kan de aanbesteder het niveau van de 4D BIM uitvraag verlagen, behouden of zelfs verhogen door de BIM-vaardigheid van partijen mee te nemen in de pre-kwalificatiefase (bijv. als onderdeel van geschiktheidseisen).

Daarnaast is het aanbevolen om een definitie van 4D BIM te geven. In de definitie van 4D BIM kan de aanbesteder ook de standaarden en gerelateerde definities (bijvoorbeeld voor het begrip LOD-niveau) die in de aanbesteding gehanteerd worden, specificeren. Op deze manier kunnen misverstanden worden voorkomen.

In de volgende paragrafen worden de aanbevelingen m.b.t. 4D BIM gegeven. De aanbevelingen zijn verdeeld in verschillende aspecten: de doelstelling en scope van de 4D BIM uitvraag, de eisen aan en de uitwerking van het 4D model behandeld, en de beoordeling van de ingediende 4D modellen.

Doelstellingen en scope

De reden om 4D BIM uit te vragen in de tenderfase is om te sturen op minder hinder, veiligheid, maakbaarheid/onderhoudbaarheid en duurzaamheid tijdens zowel de bouwfase als de gebruiks- en onderhoudsfasen. Doelstellingen om 4D BIM uit te vragen zijn het minimaliseren van het aantal voertuigverliesuren, het aantal voertuigkilometers en de CO2 uitstoot.

Andere doelstellingen moeten echter ook nog gedefinieerd worden om 4D BIM succesvol te kunnen uitvragen. De aanbesteder is aanbevolen om duidelijke en specifieke doelen voor elk 4D model te definiëren. Voorbeelden van specifieke doelen van 4D modellen zijn:

- Toon aan middels het 4D model de continuïteit van de primaire functies van het sluizencomplex gedurende het hele bouwproces
- Toon aan middels het 4D model de beschikbaarheid van het sluizencomplex gedurende het hele bouwproces waarin er rekening wordt gehouden met de effecten van de aangeboden beheersmaatregelen
- Toon aan middels het 4D model de omvang van verschillende soorten van hinder (bijvoorbeeld: de reikwijdte van geluidshinder en welke aangetaste wegen) gedurende het hele bouwproces waarin er rekening wordt gehouden met de effecten van de aangeboden beheersmaatregelen

Door zulke doelstellingen te definiëren wordt het voor de gegadigden duidelijk wat de aanbestedende dienst precies wil zien in een 4D model en kan de gegadigde zelf bepalen op welke Level of Development (LOD) het model uit te werken. Zo kan de aanbestedende dienst ook nuttig gebruik maken van de aangeleverde modellen door de informatie die zij zochten te kunnen halen uit het model. Daarnaast kan de aanbestedende dienst hiermee ook bepalen of het zinvol is om voor een specifieke doelstelling 4D BIM uit te vragen, of bepalen dat een 3D model of een film/presentatie meer geschikt is.

Een voorbeeld van een doelstelling waarvoor alleen het 4D BIM niet het meest geschikt is, is de analyse van bouwverkeerstromen op het verkeer. Om deze doelstelling te bereiken wordt de aanbesteder geadviseerd om de verkeersmodellen van het projectgebied aan de gegadigden ter beschikking te stellen. De gegadigden kunnen dan de verkeersmodellen gebruiken om de effecten van verschillende alternatieven van hun planning en verkeersmaatregelen op het wegverkeer te analyseren en te optimaliseren. De hoeveelheden materiaal per fase van hun alternatieve planningen kunnen uit het 4D model worden geëxporteerd naar een spreadsheet. Door de hoeveelheden te verdelen door de capaciteit van de gekozen vervoersmiddel kan het aantal bouwverkeerstromen worden bepaald en ingevoerd in het verkeersmodel. Door middel van het verkeersmodel kunnen de gegadigden aantonen wat het effect van hun planning en verkeersmaatregelen is op het wegverkeer.

Eisen aan en uitwerking van het 4D model

Voor de eisen aan en de uitwerking van het 4D model is het aanbevolen om een ILS 4D BIM op te stellen. In een Informatieleveringsspecificatie (ILS) zijn eisen gesteld ten behoeve van de digitale overdracht van informatie tussen de Aanbesteder/Opdrachtgever en de Gegadigde/Opdrachtnemer tijdens de tenderfase en de duur van de overeenkomst. Een ILS 4D bevat eisen ten aanzien van:

1) Algemene aspecten van de informatielevering (zoals toe te passen bestandsformaten en structuren)
2) Actief te leveren 4D model, met specifieke eisen over:
    a. Het leveringsproces
    b. Te leveren informatie
    c. De vorm van de informatie
    d. De kwaliteit van de informatie
    e. Toetsaspecten

In relatie tot de bestandsformaten wordt de aanbesteder aanbevolen om de uitvraag niet te beperken tot IFC. Aanbeveling is om de keuze aan de gegadigden te laten met de beperking dat het model dient door de aanbesteder met een, in de markt, vrij toegankelijke viewer bekeken te kunnen worden.

In relatie tot de uitwerking van het 4D model wordt de aanbesteder geadviseerd om vooraf de grafische instellingen af te spreken met de gegadigden om consistentie te krijgen in de weergave van elementen (bijv. wegen en grond), status (bijv. beschikbaar en niet beschikbaar) en activiteiten (bijv. bouwen en slopen). De gegadigden kunnen ook gevraagd worden om viewpoints te definiëren zodat de aanbesteder het model op de juiste invalshoek kan bekijken.

Beoordeling

Ten eerste wordt de aanbesteder aanbevolen om het BIM model niet als geldigheidsproduct uit te vragen. De modellen zijn opgesteld o.b.v. een ontwerpvisie met een bandbreedte van soms 20% - 30%. In een tender kan dit bandbreedte makkelijk 50% zijn. Als geldigheidsproduct is het model dus geldig binnen een bepaalde bandbreedte. De bandbreedte van het model moet dus bekend worden, alleen is het moeilijk om de bandbreedte van een model te bepalen want het verschilt per element. Er bestaat ook geen standaarden om dit te bepalen. Daarnaast kan op een tekening dingen gemakkelijk weg gelaten worden, wat niet noodzakelijk is voor bijvoorbeeld een vergunningsaanvraag. In een model kan dat niet. De ontvanger van het model kan kiezen om alles te tonen (unhide all), terwijl sommige elementen in het model eigenlijk nog niet uitgewerkt zijn, of de keuze is nog niet gemaakt. Dus men kan snel in een discussie raken waarbij elke keer toe gegrepen wordt naar het tendermodel. Maar BIM als een eis na gunning kan absoluut wel.

Ten tweede wordt de aanbesteder aanbevolen om de 4D BIM uitvraag te koppelen aan kwalitatieve EMVI-criteria gerelateerd aan bouwlogistiek en planning. Deze EMVI-criteria zijn vaak gebonden met specifieke uitdagingen in het project. Door het koppelen van de 4D BIM uitvraag aan bouwlogistieke kwaliteit krijgen de gegadigden een nauwkeurig idee over wat de doelstellingen van de aanbesteder zijn. De gegadigden kunnen middels 4D BIM de aantoonbaarheid en "SMART-heid" van hun maatregelen aantonen. Het model helpt dus de gegadigde bij de onderbouwing van wat die aanbiedt. Een ander voordeel van de koppeling tussen 4D BIM en bijv. het EMVI-criterium Bouwlogistieke Kwaliteit is dat de aanbesteder een aparte set van beoordelingscriteria hoeft te maken. Vaak heeft de aanbesteder al een set beoordelingscriteria ontwikkeld voor het EMVI-criterium, welke gebruikt kunnen worden om de resultaten van de 4D BIM uitvraag te beoordelen. Op deze manier blijft de focus op de kern issues en worden de gegadigden niet verder opgezadeld met meer criteria.

Ter aanvulling van de EMVI kan bij de aanbesteding ook vragen worden gesteld over de volgende aspecten van 4D BIM:

1) Organisatie en werkwijze (na gunning)
    a. Beschrijf uw BIM team structuur (organigram met disciplines, functies, verantwoordelijkheden en delegatielijnen).
    b. Hoe borgt u integratie van 3D en 4D BIM in uw projectorganisatie?
    c. Breng uw BIM proces in kaart (processchema waarin relatie tussen disciplines en activiteiten op hoofdlijnen wordt weergegeven, gespiegeld aan het project informatie processchema en daarin benoemde faseringen).
2) Data management (na gunning)
    a. Zijn alle BIM data op dezelfde gestructureerde manier vastgelegd?
    b. Wordt er met BIM standaarden voor de uitwisseling van data gewerkt?
    c. Hoe wordt de actualiteit van actuele gegevens gegarandeerd?
    d. Hoe wordt de kwaliteit van de BIM data bewaakt?
3) Ketenregie (na gunning)
    a. Welke criteria voor de BIM-vaardigheid worden gebruikt bij het selecteren van onderaannemers en leveranciers?
    b. Hoe worden de gegevens in de keten gedeeld?
    c. Hoe worden de onderaannemers en leveranciers betrokken bij de BIM werkwijze?

Ten slotte wordt de aanbesteder aanbevolen om een overleg, zoals de wrap-up sessie in de tender van NST, te houden waarin gegadigden hun uiteindelijke 4D modellen kunnen presenteren. Daarnaast kunnen de gegadigden gevraagd worden om een 4D BIM Plan van Aanpak in te dienen, met daarin een handleiding en specificatie voor de aangeleverde modellen.

H.1.5. Vervolgstappen

Uit de ervaring met het gebruik van 4D BIM in de casestudie NST blijkt dat dit tot aanzienlijke besparingen, minder CO2 uitstoot en minder hinder voor de omgeving kan leiden. Dit past idealiter bij de I&W beleidsthema zoals bereikbaarheid van de netwerken, klimaat en CO2 reductie. Daarmee is doorontwikkeling van 4D BIM en toepassing in projecten wenselijk. Hiervoor zijn volgende stappen op hoofdlijnen aangegeven:

1) De kennis uit dit onderzoek zullen aan contractmanagers en projectmanagers overgedragen moeten worden om potentiële projecten voor vervolg onderzoek te kunnen verkrijgen. Vervolg onderzoek is echter nog nodig om de aanbevelingen m.b.t. het uitvragen van 4D BIM en de ILS 4D BIM door te ontwikkelen voordat het een standaard binnen RWS en de markt wordt.
2) Voor het uitvoeren van het toepassingsgericht vervolg onderzoek zou RWS de samenwerking met de Universiteit Twente moeten continueren. De onderzoeksresultaten zijn input voor aanscherping van de aanbevelingen en de ILS 4D BIM.
3) De scope van RWS BIM programma zou uitgebreid kunnen worden met 4D BIM aspecten. Door het meenemen van 4D BIM aspecten kan RWS ervoor zorgen dat de aanbevelingen en de ILS 4D BIM verheven kunnen worden tot markt standaard.
4) Ten slotte, bewustwording bij opdrachtgevers, beheerders en op projectniveau van de kansen van 4D BIM in relatie tot CO2 reductie en het voorkomen van hinder tijdens de uitvoering moet gestimuleerd worden. Er moet meer nadruk komen op het belang van slimme bouwlogistiek binnen alle infrastructurele projecten.

Appendix I. Sources – BIM requirements

Table 40. Sources of BIM requirements.

#	BIM requirement	Sources
A1	3D model/ design It is possible for the client to supply a 3D model to the prime contractor. During the tender phase, the model serves as a design intent model, showing the architectural and engineering intentions of the designers. For renovation projects, the client can also supply the 'As-maintained' 3D model of the facility to the prime contractor. The as-maintained 3D model reflects all the maintenance activities and any changes made to the facility during the operation and maintenance phase in the model. When the client supplies a 3D model to the prime contractor, the **client should ensure that the 3D model is correct and reliable**. Furthermore, the client should ensure that the 3D model was produced using standardized processes and agreed standards and methods, which the client should report in an accompanying BIM protocol. This enables the information in the 3D model to be used and reused by the prime contractor. On the other hand, if the client waives responsibility and liability, then the prime contractor needs to invest time and resources to check the reliability of the model and eventually correct the errors in the model.	(British Standards Institution, 2013; Chao-Duivis, 2009)
A2	3D model as basis for engineering and production Generic BIM requirements for subcontractors and suppliers to enable the use of 3D model as basis for developing production models are detailed by Eastman et al. (2011, pp. 328-333). Information that should be included in the model are **3D geometry, material specifications, finishing requirements, and delivery sequence**. Another requirement is the ability to group components according to criteria specified by subcontractors and suppliers on the basis of their geometric information and order of assembly to manage production, procurement of parts and shipping. For this, the prime contractor (or designer, in the case of integrated contracts) would have to invest time and resources in an earlier phase of the project to develop the model for its use and reuse by project partners later on in the project. Agreements must be made between the involved parties regarding the distribution and compensation of the BIM activities.	Eastman et al. (2011)
A3	3D production model Specialist subcontractors and suppliers should deliver 3D production models to the prime contractor for (partly automated) control of clashes and other errors.	Eastman et al. (2011)
		1/3

Continuation of Table 40. Sources of BIM requirements.

A4	3D model/ design In integrated contracts, the prime contractor can contract the designer to produce a 3D model of the design. For this, the prime contractor and designers must agree on terminologies, standard procedures and modeling agreements. Access rights and permissions based on each participant's role and responsibilities should be setup as well. The scoping of the data exchange using BIM is also critical for its application. Additional agreements should also be made regarding coordination and model management, to manage and resolve clashes, model conflicts and object duplication. For the prime contractor to be able to use the 3D model for logistics, the designer should produce the following information (Eastman et al., 2011, p. 269): - **Detailed building information**, which provides graphical views of the facility's components comparable to those shown in typical construction drawings for the prime contractor to generate and extract information (such as quantity and component property information). This data is needed for procurement, installation, and commissioning. - **Analysis data related to performance levels and project requirements**, such as "structural loads, connection reactions and maximum expected movements and shear, heating and cooling loads for tonnage of HVAC systems, … and the like". This data is needed for procurement, fabrication, and MEP detailing. This information would be used by the prime contractor, subcontractors and suppliers downstream the construction process. The prime contractor should consider how to adequately motivate the designer to produce the 3D model that can be (re)used downstream the construction process.	Eastman et al. (2011)
B2	Project status and procurement tracking Each component can have a field named "Status". Values may be "approved for construction review", "in fabrication", "in delivery", and so forth, which can be associated with colors to quickly determine the status of the facility and identify bottlenecks or areas that are behind schedule. For this, subcontractors and suppliers have to supply data on the **status and location of services and materials**. This can be achieved by linking GPS technologies and RFID tags with the 3D/4D model.	(Eastman et al., 2011; Zuiker, 2012)
B3	4D model **Visualization of detailed planning** of a construction operation, to pull delivery of prefabricated parts to the construction site in a just-in-time arrangement. This includes a building model and a model of temporary facilities and cranes for a step-by-step planning and simulation of the installation sequence. The subcontractors and suppliers should also have **access to up-to-date 4D model**, to check the status of activities and eventually adjust the schedule of deliveries according to the progress of work on site.	Interview - subcontractor (N31 Highway Harlingen); (Hartmann & Fischer, 2007; Trebbe et al., 2015)
		2/3

Continuation of Table 40. Sources of BIM requirements.

B4	Level of detail and decomposition of objects In addition to BIM requirement #A3 (see Table 25), Eastman et al. (2011, pp. 290-292) lists BIM requirements for preparing and developing a 4D model: - **Model scope and level of detail** – to develop a 4D model of a detailed schedule, then the 3D model should also be developed into a higher level of detail. - **Decomposition and aggregation** – planners should be able to decompose and aggregate objects into portions to show how they will be constructed. The designer should align the production of the 3D model with the needs of the planner early on in the design phase. Since the above activities are not traditionally conducted by designers, agreements must be made between the prime contractor and designers regarding possible compensation schemes.	Eastman et al. (2011)
B5	Data on existing road networks Model of existing road networks, with data on capacity and estimated use of existing road network, which the prime contractor can use as basis for analyzing the effects of alternative construction phase planning on traffic.	TAR: New Lock Terneuzen
B6	4D model 4D model demonstrating the effects of planned construction activities and risk mitigation strategies on traffic and availability of public and temporary roads during the execution phase.	TAR: New Lock Terneuzen
		3/3

Appendix J. List of interviewees

Table 41. List of BIM managers and BIM experts interviewed.

Sector	Interviewed organizations
GWW/Civil structures	1 Client 2 Prime contractors 1 Designer
B&U/Commercial & Industrial	1 Client 7 Prime contractors 1 Subcontractor (MEP)

Table 42. List of contract managers and purchasing managers interviewed.

Interviewee	Function
Wim van de Koot	Contract manager, Ballast Nedam
Helen Miley	Contract manager, Rijkswaterstaat - SAA1
David van Hasselt	Contract manager, Alliance - N31 Traverse Harlingen
Chris Evering	Project manager, Ballast Nedam - N31 Traverse Harlingen
Olger Bos	Purchasing manager, Ballast Nedam - N31 Traverse Harlingen

Appendix K. Expert opinion 1

Number of participants

1	Client
6	Prime contractors
3	Designers
0	Subcontractors and suppliers
7	Knowledge institutes

Participants' responses

Requirement	Score	Client	Prime contractor	Designer	Subcontractor/ supplier	Knowledge institute
1	5		4	2		6
	4		1			1
	3					
	2	1				
	1		1			
2	5	1	2			3
	4		3	1		2
	3		1	1		1
	2					
	1					1
3	5		3	1		2
	4		3	1		3
	3	1				2
	2					
	1					
4	5		3	2		4
	4		2			2
	3					1
	2	1	1			
	1					
5	5		4	1		5
	4	1	1			2
	3		1	1		
	2					
	1					
6	5		3			3
	4	1	1	2		3
	3		2			
	2					
	1					1

7	5		5	2	3
	4		1		3
	3				2
	2	1			
	1				
8	5		2		1
	4		4	2	5
	3				1
	2				
	1	1			
9	5		3	2	4
	4		3		3
	3				
	2	1			
	1				
10	5		2	1	2
	4		3	1	5
	3	1	1		
	2				
	1				
11	5		2		1
	4			1	4
	3		2	1	1
	2	1	1		
	1		1		1
12	5			1	
	4		4	1	3
	3	1	2		3
	2				
	1				1
13	5		2		1
	4		4	1	3
	3			1	3
	2	1			
	1				

Solution	Score	Client	Prime contractor	Designer	Subcontractor/ supplier	Knowledge institute
1	5		4	1		4
	4	1	2	1		3
	3					
	2					
	1					
2	5		3	1		2
	4	1	2	1		4
	3					1
	2					
	1					
3 and 5	5		3	1		
	4	1	1	1		5
	3					2
	2		1			
	1					
4	5		1			
	4	1	4			5
	3			1		2
	2					
	1		1			
6	5		2	1		1
	4	1	4			4
	3			1		2
	2					
	1					
7	5		2			1
	4	1	4	1		3
	3					3
	2					
	1					
8	5		3			1
	4	1	2	1		5
	3					1
	2					
	1					
9	5		2	1		1
	4	1	3			3
	3		1			3
	2					
	1					
10	5		1			
	4		3	1		4
	3	1	1			2

	2		1				
	1						
11	5		2				
	4	1	1	1			3
	3		3				3
	2						
	1						

Appendix L. Incentive #1: Sharing of savings

1. NEEDS & GOALS OF ORGANIZATIONS

Based on the descriptions of the BIM scenarios for construction logistics, it is found that the client, prime contractor, designers, subcontractors and suppliers need to participate in the application of the BIM scenarios and deliver information for the successful use of the scenarios. However, the potential benefits of the BIM scenarios for construction logistics is not equal for all these organizations.

The differences in potential benefits may result to differences in motivation to apply BIM scenarios for construction logistics in a project. To motivate organizations to apply BIM scenarios for construction logistics in a project, additional incentives can be applied.

2. INCENTIVE: SHARING OF SAVINGS

Prime contractors, designers, subcontractors and suppliers can be incentivized to perform better using BIM by sharing the savings generated from the use of BIM scenarios for construction logistics. When savings are shared among these organizations, then they are motivated to apply BIM scenarios to reduce errors in the design and to optimize design and logistics. This incentive is applicable to the 1st layer and 2nd layer relationships, within integrated collaboration settings. Integrated collaboration settings provide a very suitable basis for sharing of savings, since they provide a judicial framework from which parties can model their contract. In addition, they allow for the early and close involvement of parties (i.e. involvement during the design phase and ability to influence the design), which is necessary for parties to influence and optimize the design (RRBouw, 2004).

3. SUGGESTED APPLICATION

One way to (generate and) share savings using BIM scenarios for construction logistics is through the principle of value engineering. During contract formulation, organizations can agree to apply value engineering and stipulate in their contract a percentage of distribution of savings. During the design phase, the prime contractor (possibly with input from subcontractors and suppliers) formulates measures/strategies to optimize design and logistics. The prime contractor could pay the designer for the BIM activities related to these strategies (such as adjusting the BIM model, and/or adding information to the model). In addition, actual savings realized by the prime contractor during the execution phase resulting from these strategies will be shared with the designer (according to a predetermined percentage of distribution). This would motivate the designer to ensure that the BIM model is created in a manner that it could be used to realize the savings (during the execution phase).

For example, the prime contractor has thought of a logistics optimization strategy that will save him €200.000. However, this strategy requires that the design model has to be adjusted and that attributes are to be added in the model. Adjusting the design model and adding the attributes would cost €120.000 for the designer. For the project, this would mean a savings of €80.000. The prime contractor pays the designer €120.000 for the BIM services. When the savings of €80.000 are actually realized, then the savings would be distributed among the prime contractor and the designer (according to a predetermined percentage of distribution).

Agreements regarding sharing of savings are usually stipulated in the contract itself. For agreements regarding the application of value engineering using BIM, the purchasing contract can include the following stipulation:

“If the contracted party sees opportunities to carry out the work more efficiently, less expensive and/or faster (‘Value Engineering’), he will inform the contracting party of this by means of a change request. Either party will subsequently draft a change request regarding the potential Value Engineering, including the potential (time) savings, as well as a proposal for the distribution of these savings. A proposal for Value Engineering can only be conducted by the contracted party if the contracting party has given a written order for this. The contracting party has the right to reject a Value Engineering proposal without stating reasons, and without having to compensate anything to the contracted party.”

Footnotes:

Sharing of savings requires transparency and trust from both parties. The organizations have to be transparent in the costs and savings they (will) incur, and they have to trust each other that these costs and savings are accurate.

Appendix M. Incentive #2: MEAT criterion 4D BIM & construction logistics

1. NEEDS & GOALS OF ORGANIZATIONS

BIM scenario #2 (4D modeling) could support construction logistics optimization and minimize nuisance to traffic caused by construction activities during the execution phase. For this, the prime contractor should deliver a 4D model to the client in the tender phase.

2. INCENTIVE: MEAT CRITERION 4D BIM & CONSTRUCTION LOGISTICS

The MEAT (most economically advantageous tender) criteria are a set of criteria used to compare bids and to determine the winning bid. Instead of comparing the bids on the basis of lowest price alone, bids are compared on the basis of both quality and price. The use of the MEAT criteria could increase the motivation of the prime contractor to think of the objectives of the client for a better chance of being awarded the contract (PIANOo, 2014a).

The MEAT criterion 4D BIM & Construction logistics is aimed to motivate the prime contractor to optimize logistics and to minimize nuisance to traffic using 4D BIM. This incentive is applicable to the 1st layer relationship (client – prime contractor), and can best be applied in integrated contract projects, wherein the prime contractor has the possibility to influence design and optimize construction logistics.

This incentive influences the personal and external motivation of the prime contractor to apply 4D modeling in a project. External motivation is influenced because 4D modeling is prescribed by the client. Personal motivation is influenced by three potential benefits (related to this incentive) of 4D modeling perceived by the prime contractor:

1) 4D modeling supports the prime contractor in optimizing logistics
2) 4D modeling supports the prime contractor in developing (more) effective strategies for mitigating the risk of nuisance to traffic
3) 4D modeling supports the prime contractor in proving and demonstrating the effectiveness of his logistics plan and risk mitigation strategies

These benefits of 4D modeling increase the chance of the prime contractor in winning the tender, and therefore positively influences his personal motivation to apply 4D modeling in a project.

3. SUGGESTED APPLICATION

The suggestions presented in this report supplement the guidebook of Taskforce Doorstroming (2009). Taskforce Doorstroming (2009) (which includes Bouwend Nederland, Rijkswaterstaat, ANWB and ProRail) has released a guidebook for project managers, contract managers, environment managers, traffic advisers and purchasing advisers of clients and prime contractors on how to effectively formulate and apply a MEAT criterion for minimizing nuisance to traffic. This incentive adds suggestion to the guidebook on how to link 4D modeling to the MEAT criterion.

Goals for linking 4D modeling to the MEAT criterion Construction logistics:

The goal of linking 4D models to the MEAT criterion Construction logistics is to steer the prime contractor to optimize construction logistics and minimize nuisance to the public during the execution phase. The linking of 4D models contributes to this goal by:

- Forcing the prime contractor to thoroughly think about and work out his MEAT strategies using 4D modeling
- Supporting the prime contractor in proving and demonstrating the effectiveness of MEAT strategies
- Supporting the client's tender and evaluation committee in understanding the (effects of) proposed MEAT strategies and consequently be more able to steer the prime contractor to the desired effects

General requirements on the 4D model:

The client is advised not to limit the request to IFC. Recommendation is to leave the choice to the prime contractor, with the condition that the 4D model must be viewable by the client with a viewer that is freely accessible in the market. The prime contractor is also requested to submit a document explaining the contents of the 4D model (such as meanings of representations and color schemes) and instructions for installing the 4D model viewer.

In relation to other file formats, the client is advised to prescribe open file formats for exchanging 3D models. The table below gives an example of file formats for each file type, which the client can use for prescription.

File type	Editable format	Read-only format
Text	DOC Word	PDF/A
3D model	IFC, RVT, LandXML	IFC, DWG, DXF, DWF, 3D PDF
Schedule	MPX, PLF, XER	PDF/A
Photo	TIFF	PDF/A, JPG, TIFF
Video	Mpeg	

Content of the 4D model:

The contents of the 4D model should be aligned with other documents submitted by the prime contractor. For example, phase planning drawings and schedules submitted by the prime contractor for the tender should be in accordance with the information in the 4D model.

The client must take care not to dictate the contents of the 4D model. The prime contractor should be given the freedom to determine how the 4D model should be setup and filled in. This includes the level-of-detail of the 4D model. Instead, the client is advised to specify functional requirements of the 4D model, by specifying what the 4D model should show.

Examples of functional requirements that the client could specify are:

- The 4D model should demonstrate the continuity of the primary functions of the infrastructure/facility throughout the construction process
- The 4D model should demonstrate the availability of the facility throughout the construction process, taking into account the effects of the proposed MEAT strategies
- The 4D model should visualize the extent of different types of nuisance (for example: the extent of noise nuisance and which roads/areas are affected) during the entire construction process in which the effects of the proposed MEAT strategies are taken into account.

For demonstrating his MEAT strategies and their effects, the prime contractor should define viewpoints in the 4D model. Viewpoints are snapshots of the model, which are taken in a specific perspective and can contain comments and tags. They support the review of the model by taking the reviewer to a predefined perspective from which to (begin to) view the model.

In addition to the 4D model itself, the prime contractor could be requested to submit a BIM Protocol/Execution Plan, which details the following aspects (Hogeschool van Amsterdam, 2015):

1) Organization and method (after award)
   a) Describe your BIM team structure (organization chart with disciplines, functions, responsibilities and delegation lines).
   b) How do you ensure integration of 3D and 4D BIM in your project organization?
   c) Describe your BIM process (process diagram in which the relationship between disciplines and activities is shown in outline, mirrored to the project information process diagram).
2) Data management (after award)
   a) Are all BIM data recorded in a similar structured way?
   b) Are BIM standards used for the exchange of data?
   c) How is the actuality of BIM data guaranteed?
   d) How is the quality of the BIM data monitored?
3) Supply chain management (after award)
   a) Which criteria in relation to BIM are used when selecting subcontractors and suppliers?
   b) How are BIM data shared among project partners?
   c) How are the subcontractors and suppliers involved in the BIM process?

Evaluation of the 4D model:
The submitted 4D models and accompanying BIM Protocol/Execution Plan should be evaluated in connection with the MEAT strategies. The prime contractor will earn points/fictional price reductions if the submitted 4D models demonstrate the effectiveness of the MEAT strategies.

The effectiveness of the MEAT strategies could be evaluated based on the following four criteria (see Taskforce Doorstroming (2009) for further information on these criteria):

1) Degree of nuisance (hinderklasse)
2) Category of nuisance (hindercategorie)
3) Duration of nuisance (hinderperiode)
4) Risk of delay

The 4D model can be used similarly to an existing tool (DuboCalc), which supports Rijkswaterstaat's MEAT criterion on sustainability. This means that the quality of the 4D model itself won't be evaluated. Instead, the evaluation will focus on the proposed strategies and their effects that are demonstrated by the 4D model. The evaluation of the bids for the MEAT criterion 4D BIM and construction logistics will then be conducted as follows:

1) The offer indicates which degree, category and duration of nuisance (referred to as nuisance mitigation strategy performance) is offered. The indication is given in the form of a number or category (see Taskforce Doorstroming (2009)) and should be supported by the 4D BIM. This means that the 4D BIM should demonstrate and coincide with the offered nuisance mitigation strategy performance.
2) A percentage is deducted from the bid price due to the nuisance mitigation strategy performance. We call this amount A.
3) The client determines which combination of degree, category and duration of nuisance scores a 6 and which a 10.
4) The MEAT score is determined on the basis of the promised performance. With this score, the MEAT amount is calculated using the MEAT calculation system. This amount (together with the amounts for the other MEAT criteria) is deducted from amount A and gives amount B (both fictitious amounts).
5) The lowest fictitious amount B of all offers wins the tender

Footnotes:

In applying the MEAT criterion 4D BIM & construction logistics, the client should consider both the effort required from the prime contractor to develop his risk mitigation strategies, and the effort required from the client's tender evaluation committee to judge the submitted risk mitigation strategies. The former could be reduced by:

1) Considerable input from the client – the client could provide the prime contractor with information such as traffic simulation models, and estimated capacity & use of existing road networks
2) Innovative procurement methods – the client could make use of innovative procurement methods, wherein the client and a preselected prime contractor enter into a collaboration to explore possible solutions to complex problems. Through this collaboration, tender costs for both parties can be minimized.

Appendix N. ILS 4D BIM

1. INLEIDING

Ten behoeve van de digitale overdracht van 4D bouwwerkinformatiemodel (BIM) tussen Gegadigde/Opdrachtnemer en Aanbesteder/Opdrachtgever tijdens de tenderfase en de duur van de overeenkomst, is een Informatieleveringsspecificatie 4D BIM van toepassing (afgekort met ILS 4D BIM).

Door middel van de ILS 4D BIM worden eisen gesteld ten aanzien van:

- Algemene aspecten van de informatielevering
- Actief te leveren 4D model, met specifieke eisen over:
    - Het leveringsproces
    - Te leveren informatie
    - De vorm van de informatie
    - Toetsaspecten

Een bouwwerkinformatiemodel (BIM) is een digitale representatie van hoe een bouwwerk is ontworpen, wordt gerealiseerd en/of daadwerkelijk is gebouwd. 4D BIM betekent dat het BIM naast de 3D-geometrische informatie en niet-geometrische informatie, ook informatie gerelateerd aan het tijdsaspect bevat.

Met de toepassing van 4D BIM streeft de Aanbesteder/Opdrachtgever de volgende doelen na:

1) Efficiënte bouwlogistiek waar sneller, slimmer en duurzamer wordt gebouwd. Hierdoor is er minder overlast voor de omgeving, minder luchtvervuiling en aanzienlijke besparingen voor alle partijen binnen de bouwlogistieke keten.
2) Gestructureerde informatieopslag en beheer die passend is voor de tenderfase, bouwfase, overdrachtsfase, alsmede de beheer- en onderhoudsfase.
3) Eenvoudige en snelle toegang tot bouwwerkinformatie voor Aanbesteder/Opdrachtgever en Gegadigde/Opdrachtnemer gedurende het hele bouwproces, zodat alle partijen beschikken over een goede informatiepositie.

Ten behoeve van de bovenvermelde doelen zijn een drietal BIM documenten van belang. In de volgende paragraaf wordt de samenhang van deze documenten toegelicht.

1.1. Samenhang met andere BIM documenten

In het digitale bouwproces zijn de ILS, het BIM Protocol en het BIM Uitvoeringsplan onmisbare documenten. De ILS behoort bij de Vraagspecificatie Proces en, zoals boven is vermeld, bevat eisen ten behoeve van BIM-leveringen tijdens de tender, bouw en oplevering. Het BIM Protocol maakt deel uit van de Overeenkomst tussen de Opdrachtgever en de Opdrachtnemer. Het BIM Protocol bevat informatie en voorwaarden aanvullend op de Overeenkomst ten aanzien van de verplichtingen en aansprakelijkheden van Opdrachtgever en Opdrachtnemer met betrekking tot te leveren BIM-modellen en/of –data, alsmede het gebruik en het eigendom van die modellen en/of data. Het BIM Uitvoeringsplan wordt opgesteld door de gezamenlijke bouwpartners en bevat afspraken die de projectpartners hebben gemaakt (en nog zullen maken) om tenminste op de BIM-levermomenten te voldoen aan de informatiebehoeften van de Opdrachtgever, welke in de ILS en het BIM Protocol zijn gedefinieerd. Op min of meer analoge wijze worden in de ILS eisen gespecificeerd ten aanzien van WAT moet worden geleverd en in het BIM Protocol en het BIM Uitvoeringsplan afspraken vastgelegd over HOE de leveringen moet gebeuren.

2. ALGEMENE UITGANGSPUNTEN INFORMATIELEVERING

In het kader van de tender en de Overeenkomst zal Aanbesteder/Opdrachtgever gegevens ontvangen van en leveren aan de Gegadigde/Opdrachtnemer. Gegadigde/Opdrachtnemer heeft de gegevens nodig voor inschrijving en uitvoering van het contract. Aanbesteder/Opdrachtgever heeft de gegevens nodig voor de uitvoering van de beheer-, publieke en wettelijke taken.

Tijdens de tenderfase vindt de uitwisseling van gegevens tussen de Aanbesteder en de Gegadigde plaats. Na gunning en tijdens de duur van de overeenkomst vindt de uitwisseling van gegevens tussen de Opdrachtgever en Opdrachtnemer plaats. Voor eenvoud wordt de Aanbesteder hierna Opdrachtgever en de Gegadigde hierna Opdrachtnemer genoemd.

2.1. Verantwoordelijkheid van de Opdrachtnemer

De Opdrachtnemer dient ten behoeve van bouwlogistieke kwaliteit een 4D model uit te werken volgens de richtlijnen van deze ILS. Hiertoe zal de Opdrachtnemer minimaal de, in het project voorkomende, objecttypen uit de Objecttypenbibliotheek (OTL) dienen te instantiëren. Tot de verantwoordelijkheid van de Opdrachtnemer behoren hiertoe:

1) Het opstellen van het 4D model
2) Het bijhouden van het 4D model met de actuele situatie, alsmede de historie
3) Het leveren van het 4D model aan de Opdrachtgever

2.2. Verantwoordelijkheid van de Opdrachtgever

Opdrachtgever stelt de Objecttypenbibliotheek (OTL) beschikbaar. De OTL bevat onder meer een overzicht van de objecttypen, en is opgebouwd uit de volgende onderdelen:

- Gebruikershandleiding (document met opsomming van de deelproducten, een korte toelichting op de relatie met de ILS, inhoud en wijze van gebruik)
- Navigeerbare website (zip-bestand met HTML pagina's)
- COINS Objecttypelibrary (COINS owl-bestand)
- RWS Referentiekader (COINS owl-bestand)
- Document met toelichting op RWS Referentiekader
- XSD schema ten behoeve van het vastleggen van de geometrie.

Opdrachtgever stelt een interactie raamwerk beschikbaar overeenkomstig de Nederlandse VISI standaard, rel. 1.2, ref. CROW, of ISO/CD 29481-2, IDM part 2, Interaction framework.

3. EISEN INFORMATIELEVERING

3.1. Het leveringsproces

Tijdens de tenderfase zal de Opdrachtgever één of meer overleggen inplannen met betrekking tot het onderwerp 4D BIM. Opdrachtnemer dient tijdens de tenderfase zijn ontwerp in 4D BIM uit te werken, dit model te bespreken (met de applicatie van de gegadigde zelf) tijdens de overleggen en uiteindelijk aan te leveren bij inschrijving. Tijdens de tenderfase zal de uitwerking van het ontwerp en bouwfasering middels dit 4D model aantoonbaar en bespreekbaar gemaakt dienen te worden door de Opdrachtnemer. Hiervoor dienen zij een aanpak te presenteren waarin de diepgang, afstemming en werkwijze inzichtelijk gemaakt te worden.

Vanaf gunning dient de Opdrachtnemer in overleg met de Opdrachtgever een beveiligde internetomgeving op te zetten. In deze internetomgeving kunnen alle ketenpartners het integrale up-to-date model viewen. Dit integrale model mag bestaan uit meerdere modellen, die op basis van RD-coördinaten met elkaar geïntegreerd kunnen worden. Na grote wijzigingen waarbij een nieuwe situatie is ontstaan dient de Opdrachtnemer het 4D model digitaal aan te leveren.

3.2. Te leveren informatie

Het 4D model dient ten minste:

1) Te bestaan uit digitale bestanden conform de volgende specificaties:
    a) Te viewen en in te lezen op zowel geometrische als niet-geometrische data
    b) Voor iedere object(instantie) geldt een unieke objectcode (identificatie), de identifier van et moederobject en een NEN-code + eventueel een andere code ten behoeve van andere decompositiestructuur. Hiermee wordt een decompositiecodering bedoeld. Opdrachtgever wenst een logische opbouw in de structuur van het model.
    c) Gerelateerd te zijn aan het Rijksdriehoeksstelsel (RD).
2) Consistent te zijn met alle onderdelen van de inschrijving, c.q. oplevering
3) Het EMVI-plan Bouwlogistieke Kwaliteit te onderbouwen. De Opdrachtnemer kan middels 4D BIM de aantoonbaarheid en “SMART-heid” van hun maatregelen aantonen. Het model helpt dus de Opdrachtnemer bij de onderbouwing van wat die aanbiedt, c.q. heeft aangeboden.

De Opdrachtnemer dient alle native modellen ook in te leveren. Daarnaast vraagt de Opdrachtgever de Opdrachtnemer om de installatiebestanden van de nodige 4D BIM tools/viewers, samen met een handleiding ten aanzien van het gebruik van de 4D BIM tools/viewers, in te leveren.

Naast het 4D model dient de Opdrachtnemer een 4D modelleringsplan op te stellen. In het 4D modelleringsplan dient de Opdrachtnemer invulling te geven op de volgende aspecten:

1) Organisatie en werkwijze (na gunning)
    a) Beschrijf uw BIM team structuur (organigram met disciplines, functies, verantwoordelijkheden en delegatielijnen).
    b) Hoe borgt u integratie van 3D en 4D BIM in uw projectorganisatie?
    c) Breng uw BIM proces in kaart (processchema waarin relatie tussen disciplines en activiteiten op hoofdlijnen wordt weergegeven, gespiegeld aan het project informatie processchema en daarin benoemde faseringen).
2) Data management (na gunning)
    a) Zijn alle BIM data op dezelfde gestructureerde manier vastgelegd?
    b) Wordt er met BIM standaarden voor de uitwisseling van data gewerkt?
    c) Hoe wordt de actualiteit van actuele gegevens gegarandeerd?
    d) Hoe wordt de kwaliteit van de BIM data bewaakt?
3) Ketenregie (na gunning)
    a) Welke criteria voor de BIM-vaardigheid worden gebruikt bij het selecteren van onderaannemers en leveranciers?
    b) Hoe worden de gegevens in de keten gedeeld?
    c) Hoe worden de onderaannemers en leveranciers betrokken bij de BIM werkwijze?

3.3. De vorm van informatie

De informatie die in dit document is omschreven, dient geleverd te worden in de vorm van een document. De volgende tabel geeft de voorgeschreven bestandsformaten weer:

Bestandtype	Hergebruik formaat	Uitsluitend lezen formaat
Tekst	DOC Word	PDF/A
4D model*	NWD, SPX	NWD, SPX
3D model	IFC, RVT, LandXML	IFC, DWG, DXF, DWF, 3D PDF
Planning	MPX, PLF, XER	PDF/A
Foto	TIFF	PDF/A, JPG, TIFF
Video		Mpeg

*De Opdrachtgever wil, ten behoeve van het project, de bouwwerkinformatie gedurende het hele bouwproces digitaal uitwisselen op basis van open standaarden. Hiervoor vraagt de Opdrachtgever om het 4D model volgens deze open standaarden aan te leveren. Het 4D model dient door de Opdrachtgever met een, in de markt, vrij toegankelijke viewer bekeken te kunnen worden.

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Ruth Noemi Francia Sloot