MASTER THESIS

DEVELOPING A FRAMEWORK FOR THE IMPLEMENTATION OF BIM IN DUTCH INFRASTRUCTURE TENDERING.

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Developing a framework for the implementation of BIM in Dutch infrastructure tendering.

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Abstract

Every Dutch public infrastructure project above the price of 5,548,000 EUR has to be put out for a request for a tender. Large amounts of information have to be produced in a short amount of time with a new team within the tender phase. This information is not only needed to provide a correct budget estimate, but also to score points on the Most Economically Advantageous Tender (MEAT)-criteria. BIM can be applied to structure the information and produce a high qualitative bid. However, in practice, BIM is applied in an ad hoc way during the tender, and an extensive scientific basis about this phase is missing. Therefore, this study aims to develop a systematic BIM implementation framework, which will (1) help determine the scope of the implementation of BIM during the tender procedure and (2) show which steps, in relation to BIM, to take during the tender. A case study is executed to develop the framework with fifteen individual interviews with different disciplines and one group interview. The main findings of the case study are: that BIM should only be applied to support the bid; clear agreements should be developed at the start of the tender; participants should be involved through the entire process; the quality of BIM should be high; the process should be efficient; and after the bid has been won, the model should be updated. A framework was developed based on these findings. This includes four different main modules: developing a BIM-strategy; developing a BIM-model; developing bid aspects; and after the bid is submitted. A validation is performed to determine whether the framework is usable and meets the main requirements. This showed that although some minor adjustments have to be implemented, the proposed framework is functional and can be of added value at the start of a tender whenever BIM is considered.

Keywords: Building Information Modelling, competitive dialogue tender, Dutch infrastructure projects, tender phase, Most Economically Advantageous Tender

1. Introduction

Different kinds of construction projects are designed, executed, and delivered in the Netherlands every year. When there is a public project above 5,548,000 EUR , the Dutch government is obliged to put out a request for a tender to provide an equal opportunity for different companies (Chao-Duivis, Bruggeman, Koning, & Ubink, 2018; PIANOo, 2019). Different consortiums, consisting of contractors and specialist parties, submit a bid for the request of tender. Collaboration within the multidisciplinary consortium is always a challenge. Conventionally, the collaboration within the consortium in the tendering phase is unstructured and ad hoc, leading to errors, rework, and deliverables that would need to be redone if the tender is successful. However, with the advent of Building Information Modelling (BIM) in recent years, the workflows within the tendering can be potentially improved using BIM-based collaboration. The benefits of BIM are not limited to cases where a preliminary design is required in the tender because BIM can help provide a more accurate planning for the bid as well (Talebi, 2014b).

Although the tender process is important and well applied in many countries, bidders still experience many challenges. One of the challenges is the large amount of information needed during the preparation of the tender, leading to unstructured documents and therefore often mistakes in the bidding documents (Lou & Alshawi, 2009; Mohemad, Hamdan, Ali Otman, & Mohamad Noor, 2010). Mohemad et al. (2010) state that the decision making is very important during the tender phase because decisions made at the beginning of the lifecycle have a big impact at the end of construction lifecycle. However, this decision making is constrained by the fragmentation of the industry, the conflicting opinions/interests/views/ priorities of individuals, time pressure of the tender phase, unknown client's needs/wishes, and continuous changes in design due to the changing needs of the client. In this complex environment, decisions based on incomplete/inaccurate information may be suboptimal and thus can significantly impact the quality and reliability of the final design and project realization. Additionally, a new consortium needs to be formed before the start of a tender, where new collaborations arise (Arslan, Tuncan, Birgonul, & Dikmen, 2005). The Integrated Project Delivery (IPD) method can be applied to enhance the collaboration between many parties (which can include over thirty different disciplines) in the consortium. IPD ensures that people, systems, business structures, and

practices are integrated into one process, and will collaborate from the early design phase (tendering) to the project handover (The American Institute of Architects, 2007). IPD is demonstrated potentials to optimize project results, diminish the waste, and increase efficiency/value of the construction (Jones, 2014). During this process, five aspects (money, organization, time, information, and quality) need to be considered and balanced, based on the client's needs (Grit, 2015). BIM is being widely applied in large construction projects as part of the IPD strategy. BIM can be defined as a process where a 3D digital model is used to guide and structure the multidisciplinary consortiums. According to this paradigm, all project information is structured in a centralized digital model and all involved parties will access/share information and communicate through this model throughout the project lifecycle (Eastman, Teicholz, Sacks, & Liston, 2008). Furthermore, BIM can also be expanded to facilitate the implementation of planning (4D) and costs (5D) (Smith, 2016). Nevertheless, contrary to a common misconception, the implementation of BIM is not realized only through the adoption of 3D design tools, but it also requires restructuring of the traditional processes and workflows (Eastman, Teicholz, Sacks, & Liston, 2008). This requires a close collaboration, where all the key disciplines are involved from the beginning of the project (Walasek & Barszcz, 2017). However, this form of collaboration mindset/structure is seen as the most conspicuous inhibition against successful BIM implementation (Liu, van Nederveen, & Hertogh, 2017; Oraee, et al., 2019; Eadie, Browne, Odeyinka, McKeown, & McNiff, 2013). It is demonstrated that BIM can be applied to reduce loss at the tendering phase (Forgues & Iordanova, 2010). BIM can help structure the large volume of data generated during the tender phase and thus reduce the chance of errors and rework (Oh, Lee, Wan Hong, & Jeong, 2015). BIM can stimulate a more active partnership formed from the beginning of the project between the different parties, which will help the openness of the information sharing (Liu, van Nederveen, & Hertogh, 2017). BIM can also provide higher accuracy of cost estimation, due to the quantities that can be extracted from BIM and can be used for the cost calculations needed during the tender phase (Talebi, 2014b). Additionally, the presence of a BIM model allows the various types of analyses to ensure the compatibility of the design with the client's requirements. Finally, the BIM implementation in the tender phase can substantially streamline the transfer of information to the design phase and thus contribute to saving a considerable amount of time and money (Eastman, Teicholz, Sacks, & Liston, 2008). All in all, the implementation of BIM during the tendering phase is very relevant, especially for large and complex projects. Even the European directive on public procurement encourages parties to apply BIM during tendering (Ciribini, Bolpagni, & Oliveri, 2015). Currently, BIM implementation is mostly considered in the design and construction phases. In this sense, it can be posited that the current scope of BIM implementation in the construction projects seldom extends to the tendering phase. Although the beginning of the design phase seems similar to the tender phase, some characteristics make the implementation of BIM during tendering more difficult and not immediately comparable to the conceptual or schematic design phases. These characteristics include, but are not limited to, the time pressure of the tender process, the ambition to keep the costs as low as possible, uncertainty about the success of BIM and thus ambiguities about the return on investment, and lack of clarity about the client's needs/ambitions (Mohemad, Hamdan, Ali Otman, & Mohamad Noor, 2010).

However, the implementation of BIM during the tender process is still relatively new and unfamiliar for many parties in practice. In some pilot cases where BIM was implemented in the tendering phase, BIM was only applied in an unsystematic and experimental fashion, and as a result of which, the BIM implementation often fell short of its true potentials in the tendering phase (Eastman, Teicholz, Sacks, & Liston, 2008). Additionally, literature concerning the implementation of BIM in the tendering phase is scarce, especially from the bidder's perspective. So, there is a palpable gap in terms of the understanding of requirements and strategies for the successful implementation of BIM in the tendering phase. Having said that, it must be highlighted that a global and one-size-fits-all framework for the BIM implementation, especially in the tender phase, is unrealistic. Mainly because there are strong cultural, legal, procedural, and contextual dimensions to the BIM implementation framework which requires it to be tailored for each specific setting. On this premise, this research investigates the specific case of Dutch infrastructure within non-closed competitive dialogue tenders. This study aims to develop a systematic BIM implementation framework, which will (1) help determine the scope of the implementation of BIM during the tender procedure and (2) show which steps, considering BIM, to take during the tender.

2. Literature review

In the past, little to no research has been done on the application of BIM in tendering from a bidder's perspective. However, there is literature on the different elements within a competitive dialogue tender, general requirements on implementing BIM during every phase, and different BIM-uses that can be applied. The study on these literature elements will form a basis for

researching the requirements and steps taken for applying BIM during a tender.

2.1. The competitive dialogue procedure

The competitive dialogue is a well-known tender procedure in the Netherlands for big infrastructure projects. This procedure is applied for bigger and more complex projects which need innovative design solutions and provides dialogues to explain the innovative solutions from the consortium to the client (PIANOo, 2019; Ottemo, Wondimu, & Laedre, 2018; Lambropoulos, 2013).

The Most Economically Advantageous Tender (MEAT) wins the project in a competitive dialogue tender. This entails that not only the lowest price wins, but the bid will be judged on different quality criteria, which can provide a fictional discount (Ottemo, Wondimu, & Laedre, 2018). Besides the MEAT-criteria and costs, the bidders are also assessed on a valid planning. Additionally, the bidder should be confident that the infrastructure is constructible for the cost and planning that they submit at the end of the tender. The construction of the design itself will not be assessed, however, drawings of the architecture of the design might be one of the validity products. These drawings are mostly to judge the aesthetics, but not the constructability (PIANOo, 2019). All these bid aspects should be developed during the whole tender and is referred to as the bid development.

2.2. General requirements for BIM

BIM is applied within infrastructure projects during different phases. For these different phases, requirements are provided in literature to enhance the implementation of BIM. In line with many literature sources, first agreements have to be made before BIM is implemented. These agreements should be defined and written down to enhance the collaboration and to manage the expectations of the people involved during the project. As a first step, the roles and different responsibilities of every participant should be defined (Alreshidi, Mourshed, & Rezgui, 2017; Eastman, Teicholz, Sacks, & Liston, 2008). Secondly, the standards about the approach to model should be identified at the beginning of the process, so the same kind of file naming, reference points, colors and identifications for the objects, compatible file formats, etc. (Eastman, Teicholz, Sacks, & Liston, 2008; Jung & Joo, 2011; Morlhon, Pellerin, & Bourgault, 2014; Tauriainen, Marttinen, Dave, & Koskela, 2016; Zigo & Gong, 2018). Additionally, requirements, vision, goals, key performance indicators information, strategies, responsibilities, and tools needed for BIM should be identified collaboratively (Morlhon, Pellerin, & Bourgault, 2014; Alreshidi, Mourshed, & Rezgui, 2017; AIA, 2007; Yilmax, Akcamete, & Demirors, 2019). Furthermore, the phase outcomes, deliverables, and its belonging milestones should be set for the whole process (Alreshidi, Mourshed, & Rezgui, 2017; AIA, 2007; Ma, Zhang, & Li, 2018). Lastly, the objects that will be modeled and their belonging LOD (Level of development) should be defined (Tauriainen, Marttinen, Dave, & Koskela, 2016; Smith, 2016; AIA, 2007). The LOD is the level of the detail of information in the BIM-model and its related available data (Dupuis, April, Lesage, & Forgues, 2017). Moreover, to enhance BIM and its collaboration, the whole consortium should work in the same office (Eastman, Teicholz, Sacks, & Liston, 2008; AIA, 2007; Ma, Zhang, & Li, 2018; Raisbeck, Millie, & Maher, 2010). All these agreements combined can be called the BIM-strategy and will be referred to as such in this study.

Much that has been written on BIM describes different requirements on what to do during the process of implementing BIM. Firstly, the different parties should work simultaneously instead of working linearly (Eastman, Teicholz, Sacks, & Liston, 2008). Additionally, all parties should be involved from the start (Alreshidi, Mourshed, & Rezgui, 2017; Yilmax, Akcamete, & Demirors, 2019) and should be involved during the whole project, even when their task is completed (Elghaish, Abrishami, Hosseini, Abu-Samra, & Gaterell, 2019). Moreover, the design effort and time spent on the project should be at the beginning of the process (Eastman, Teicholz, Sacks, & Liston, 2008; AIA, 2007; Succar, 2009; Ma, Zhang, & Li, 2018). Also, weekly meetings should be scheduled to provide feedback and improvements on the process and the deliverables, which should then be documented and send to all participants (Yilmax, Akcamete, & Demirors, 2019; Tauriainen, Marttinen, Dave, & Koskela, 2016; Zhang & Hu, 2018). Furthermore, the decisions made during the whole project need to be made collectively, to provide insights from different perspectives (AIA, 2007; Piroozfar, et al., 2019; Ma, Zhang, & Li, 2018). 3D and 4D visualizations of BIM can be created to enhance this decision making (Wright, 2012). A BIM-manager should also be available during the process, who will be responsible for the integration of the models (Alreshidi, Mourshed, & Rezgui, 2017; Tauriainen, Marttinen, Dave, & Koskela, 2016). Finally, the less experienced parties in BIM should receive BIM training through the whole process and should be helped by the more experienced parties within the consortium (Yilmax, Akcamete, & Demirors, 2019; Alreshidi, Mourshed, & Rezgui, 2017; Eastman, Teicholz, Sacks, & Liston, 2008).

During the project and the implementation of BIM, much information needs to be exchanged. Literature defined some requirements for this as well, such as, all parties should make sure that their

information for other parties is available on time (Tauriainen, Marttinen, Dave, & Koskela, 2016). All this information should be transparent and available for all parties (Mayouf, Gerges, & Cox, 2019) and all participants should be notified when changes or decisions are made within the model (Alreshidi, Mourshed, & Rezgui, 2017; Eastman, Teicholz, Sacks, & Liston, 2008; Mayouf, Gerges, & Cox, 2019).

Literature also defines some requirements relevant to the BIM-model itself. So, it states that a 3D model should be developed with information about all objects in infrastructure, which is geometrically correct with comprehensive data, quantifiable, and query-able (Smith, 2016; Charef, Alaka, & Emmitt, 2018; Mayouf, Gerges, & Cox, 2019; Eastman, Teicholz, Sacks, & Liston, 2008). Costs and planning can be developed based on this 3D model and should be aligned with the LOD of the model (Smith, 2016; Mayouf, Gerges, & Cox, 2019). To maintain the quality of the model, a weekly meeting should be held with all representatives to find clashes/errors in the integrated model, to solve these clashes and to know what information is needed from each other for the following week (Tauriainen, Marttinen, Dave, & Koskela, 2016; Eastman, Teicholz, Sacks, & Liston, 2008; Smith, 2016). All the requirements stated above are relevant for the process of developing the BIM-model.

One last requirement is important after BIM has been implemented. An evaluation should be executed on the appliance of BIM, to determine flaws and to improve the implementation of BIM in next projects. This includes determining the BIM-uses that are most beneficial, the steps taken during the project and how it should be improved the next time (CIC, The Computer Integrated Construction Research Program, 2010; Eastman, Teicholz, Sacks, & Liston, 2008). Evaluating BIM is also important for a tender.

2.3. Application of BIM

BIM is explained differently by different people, especially on what to expect when BIM is applied. The different aspects of how BIM can be used will be defined by the definition 'BIM-uses'. Different researchers have identified the different BIM-uses, however, not all are relevant for the tender phase. Therefore, only the BIM-uses relevant for the tender will be discussed in this chapter. For these BIM-uses the 3D BIM-model is the basis, which should be developed by the modelers.

The most known BIM-use is the use of 4D-planning, where the aspect of time is linked to the 3D model. With 4D planning, it will be visualized how the infrastructure will be constructed during the construction phase (Zigo & Gong, 2018; Raisbeck, Millie, & Maher, 2010; Feng, Mustaklem, & Chen, 2011; Eastman, Teicholz, Sacks, & Liston, 2008). Furthermore, 5D BIM is a well applied BIM-use, where the costs are linked with the 3D model. For this, a bill of quantities should be provided by the BIM-model, where the right input for the model is needed (Eastman, Teicholz, Sacks, & Liston, 2008). The costs can be developed based on the bills of quantities, along with other information from the infrastructure that can be provided. To determine the costs of the infrastructure, not only the quantity of elements is needed, but labour, materials, and equipment should be defined in the model as well for better cost estimation (Zigo & Gong, 2018; Wright, 2012; Sheng Lee, Wei Tsong, & Faris Khamidi, 2016). Another well-known aspect of BIM is to enhance communication, by providing a clear design of the infrastructure. This is done by providing visualizations of the infrastructure, to show the design ideas internally and externally (Wright, 2012; Harvard, 2017).

To integrate the different models and apply clash detection, clashes between interfaces of the model can be discovered and solved before construction. This is relevant to determine whether requirements are met and whether the infrastructure is constructible (CIC, The Computer Integrated Construction Research Program, 2010; Harvard, 2017). Other clashes that can be determined, are between the infrastructure and the site layout. By implementing the infrastructure models in the site layout, the system border, the space around the infrastructure, and the depth of the surroundings can be depicted (CIC, The Computer Integrated Construction Research Program, 2010; Harvard, 2017). Additionally, relevant are the traffic measures for an infrastructure project. These can also be illustrated in the BIM-model to provide better insights on how the design will interact with the traffic measures during construction (Harvard, 2017). Lastly, parametric design is relevant when designing new constructions. With parametric design, a computer can develop many different design options and the differences in the design options within different parameters, like costs, planning, construction equations, etc. This is suitable when many design options need to be reviewed in a short amount of time (Rempling, Mathern, Ramos, & Fernandez, 2019).

3. Methodology

This research features a design-oriented research approach for developing a framework for the implementation of BIM. This was chosen, because a framework needed to be developed for the objective of this research, wherefore a design-oriented research approach is well suited (Verschuren & Hartog, 2005). The following steps need to be taken following a design-oriented research approach: developing requirements, designing a prototype, and implementing and evaluating the framework (Verschuren & Hartog, 2005). These different steps are visualized in Figure 1.

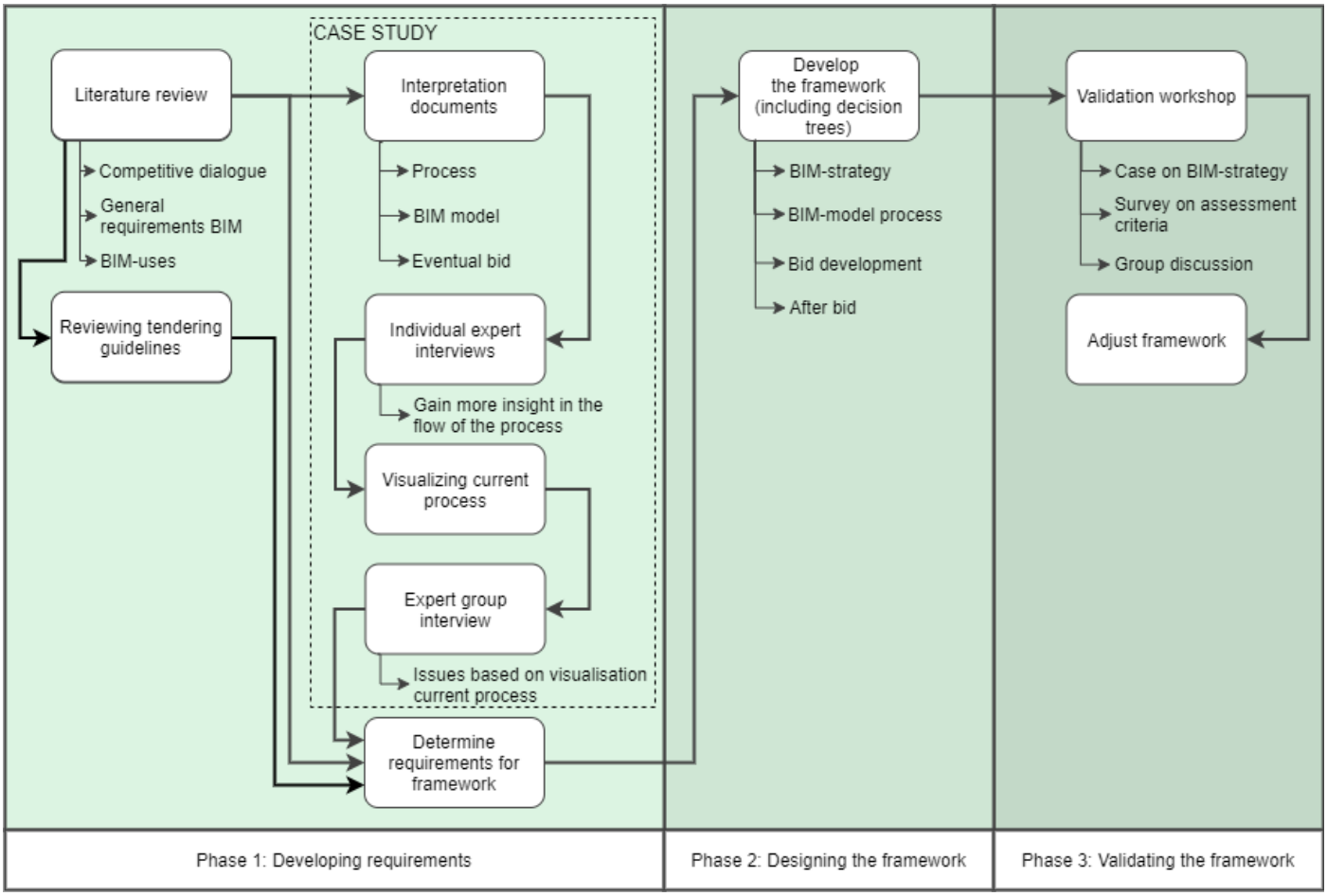

Figure 1: Methodology diagram

3.1. Developing requirements

The first phase of this research concerns the development of requirements for the implementation of BIM in tendering. A qualitative research is conducted to do so, because an in-depth and holistic view is required in this study for the development of a framework. This phase concerns an exploration of empirical data to study the process of implementing BIM in tendering. To enhance the validity and robustness of the findings, method and source triangulation is applied through the use of expert interviews, interpretation of documents, and findings from academic literature (Verschuren & Doorewaard, 2007). Additionally, the case study is chosen because it has a small unit of analysis (projects), provides more depth to the research, generates insights about the whole process (instead of only separate variables), and it develops qualitative data (Verschuren & Doorewaard, 2007). Furthermore, case studies are suitable for investigating complex phenomena, such as the implementation of BIM in tendering, as they allow for generating new and deeper understanding of the phenomenon within its respective context (Bougie, et al., 2017).

The literature discussed in the previous chapter is used as the base of developing the framework. Additionally, tendering guidelines from different big infrastructure projects were reviewed. The tendering guidelines are compared, and similarities are analysed and implemented in the framework

Following the exploration and analysis of literature and tendering document, a case study has been executed. The case study features a project involving a highway that needs to be broadened and the different civil constructions along this highway that should be renovated and or newly build. This project is chosen as a base of this framework because BIM was implemented at a high level (3D-models, some parametric design, visualizations of integration, 4D, and a bill of quantity). Due to the high-level implementation, a better overview on the current practice can be provided. The process to get to the end result was mostly unorganized, resulting in inefficiencies and possibly a lack of broader adoption within the tender phase. Therefore, this project adds value to the research.

In the process of examining this case, documents on the tender itself, documents on the process of the consortium, the bid, and the BIM-models were first reviewed. The findings of this review were used as input for the interviews. Next, 15 individual case-oriented interviews were conducted (including designers, BIM-managers, Dubocalc calculators, cost calculator, MEAT developers, constructor, planner, and tender manager).

I.D.	Role	Amount of large infrastructure tender projects	Year of experience with BIM	Tender projects including BIM	Individual interview (II) or both individual and group interview (II&IG)
1	Tender manager	8 till 10	5.5	1	(II)
2	MEAT - specialist	1	2	1	(II)
3	MEAT - specialist	3	2.5	1	(II)
4	Dubocalc (boq)	4 till 6	10	4 till 6*	(II)
5	Dubocalc (boq)	1	0,5	1	(II)
6	Cost calculation	2	8.5	1	(II)
7	Planning	1	1	1	(II&IG)
8	Head design	2	5	1	(II&IG)
9	Design (road)	2	5	2*	(II&IG)
10	Design (road)	2	6	2*	(II&IG)
11	Design (civil)	5	5	3*	(II)
12	Design (civil)	2	5	1	(II)
13	Constructor	3 till 4	3	2*	(II&IG)
14	BIM-manager	6	10	3*	(II)
15	BIM-manager	2 till 3	2.5	3*	(II&IG)

* other tender projects included BIM, but was executed at a minimum level with only 3D models and sometimes a bit of 4D-planning

Table 1: Overview of the participants of the interviews

An overview of the different interviewees is presented in Table 1. Questions on experience, role within the project, the implementation of BIM, and typical tender characteristics were asked within these interviews (a topics table of the interview is provided in Appendix A). The selected interviewees were chosen because they were involved in the selected case and had roles concerning one of the bid aspects, the design team, or BIM. Additional people were interviewed from the design team because the design team was a big team and developed the BIM model. The people interviewed had design management related roles and others were modellers. The extensive variety of roles interviewed was to get a broad overview of the involvement of the different parties and their relationship with BIM during the tender.

A visualization of the current state practice of the tender was developed based on the individual interviews, and some problems and requirements were already defined. These findings were used as input for the next step, where a group interview was conducted. The case-oriented group interview concerned six participants (including BIM-manager, constructor, planner, and designers) that had been interviewed individually as well. The same people were used because the groups interview was an elaboration on the individual interviews. However, not all participants had time to be involved in the two hours group interview at the same time, therefore, only six were involved. This was enough to provide a qualitative group discussion with different perspectives on the problems and good aspects of the current process. The group interview addressed the problems, improvements, and positive aspects of the project process (a topics table of the interview is provided in Appendix B). Table 1 shows who were also involved in the groups interview.

Requirements could be defined for the process following the completion of the group interview and the prior literature review and tendering documents assessment. This was done by transcribing the interviews and manually coding and ordering all the information.

I.D.	Role	Amount of large infrastructure tender projects	Year of experience with BIM	Tender projects including BIM
1	BIM-manager	6	10	3*
2	Constructor	1	5	1
3	MEAT - specialist	2	3	1
4	BIM-modeler	1	5	0
5	Planning	1	1.5	1
6	BIM-manager	3	8	3*

*Other tenders applied BIM, but only included 3D modeling, coordination, visualization, bill of quantities

Table 2: Overview of the participants of the validation workshop

3.2. Designing the framework

The requirements are then translated into a prototype for the realization of the framework. This prototype considered different steps of the process at the start of the tender (BIM-strategy), during the tender (BIM-model process and bid development), and at the end of tender (after bid) and was developed by different design iterations and discussions on the visualization of the framework with supervisors. Decision trees are developed to elaborate more on how some steps should be executed as well for which the requirements and input of the different interviews are used.

Assessment criteria	Description
Comprehensibility	The framework should be understandable for all parties involved.
Genericness	The framework should be generic enough for application to all big infrastructure tender projects, but it should also explain what to do during every step.
Ease of use	The framework should be easy to use and make parties willing to use the framework in the following tender projects.
Efficiency	The process will become more efficient than the ad hoc process, which means that more work can be accomplished in less time, by applying the framework.
Reliability	The reliability of the framework is assessed in terms of whether the parties involved are dragged into the entire process early enough and whether the framework is reliable to use for a tender.

Table 3: Assessment criteria descriptions

3.3. Validating the framework

After completing the initial design of the framework, the framework should be implemented and evaluated (Verschuren & Hartog, 2005). Due to time constraints, the framework could not be fully implemented in a real case. Therefore, only a small part (the BIM-strategy) was implemented. The rest of the framework was validated through an evaluation. To do this in the limited amount of time, the implementation and evaluation are combined into validating the framework in one workshop.

The validation workshop included six participants (including BIM-managers, constructor, planner, MEAT developer, and designer). An overview of the participants is provided in Table 2. These participants differ from those involved in the individual and group interviews. Moreover, they were not necessarily involved in the case project of the development of the framework. Only one participant who was involved in the individual interviews, was also involved in the validation workshop. An extra BIM-manager was needed and another one could not be found on time, hence the double involvement. Having different participants allows for gaining new insights about the framework and provides a means for triangulation, enhancing the validity of the framework (Verschuren & Doorewaard, 2007). The roles of the participants were chosen, based on the involvement of the different roles within the framework. BIM-manager is the most important role to assure the implementation of the framework, therefore, two BIM-managers were involved during the workshop.

The framework was assessed on several assessment criteria to determine the quality, including comprehensibility, genericness, ease of use, efficiency, and reliability (explained in Table 3). These assessment criteria are based on the friendliness of use of the framework and applicability. Moreover, the efficiency and the reliability are based on the requirements retrieved from the interviews. These were important on the overall process of the framework. Other requirements from the interviews concerned the different steps that had to be taken during the process instead about the whole framework and are therefore not validated. Additional to the assessment criteria, the quality of the content and improvements of the framework are discussed.

The first part of the workshop consisted of a case where the first part of the BIM-strategy component of the framework was practiced to get the participants familiar with the framework and provide an implementation. Then, a survey on the different assessment criteria and the different elements of the framework was filled out. This was done to get an individual opinion on the framework by every expert. Lastly, the results of the survey, improvements, and solutions were discussed in a group discussion. The survey and the group discussion provided an evaluation of the framework. A topics table on the validation workshop is provided in Appendix C. The interview was transcribed, and manually coded related to the assessment criteria, and the adjustments that needed to be made immediately. The statements from the case and the discussion were combined with the individual statements of the survey.

4. Interview results

First, an analysis on the current state of practice and its belonging overview is provided based on the individual interviews. Then, requirements are defined based on the individual and group interviews.

4.1. Analysis of the current state of practice

The individual interviews provided insights into the different roles that are needed during a tender and what

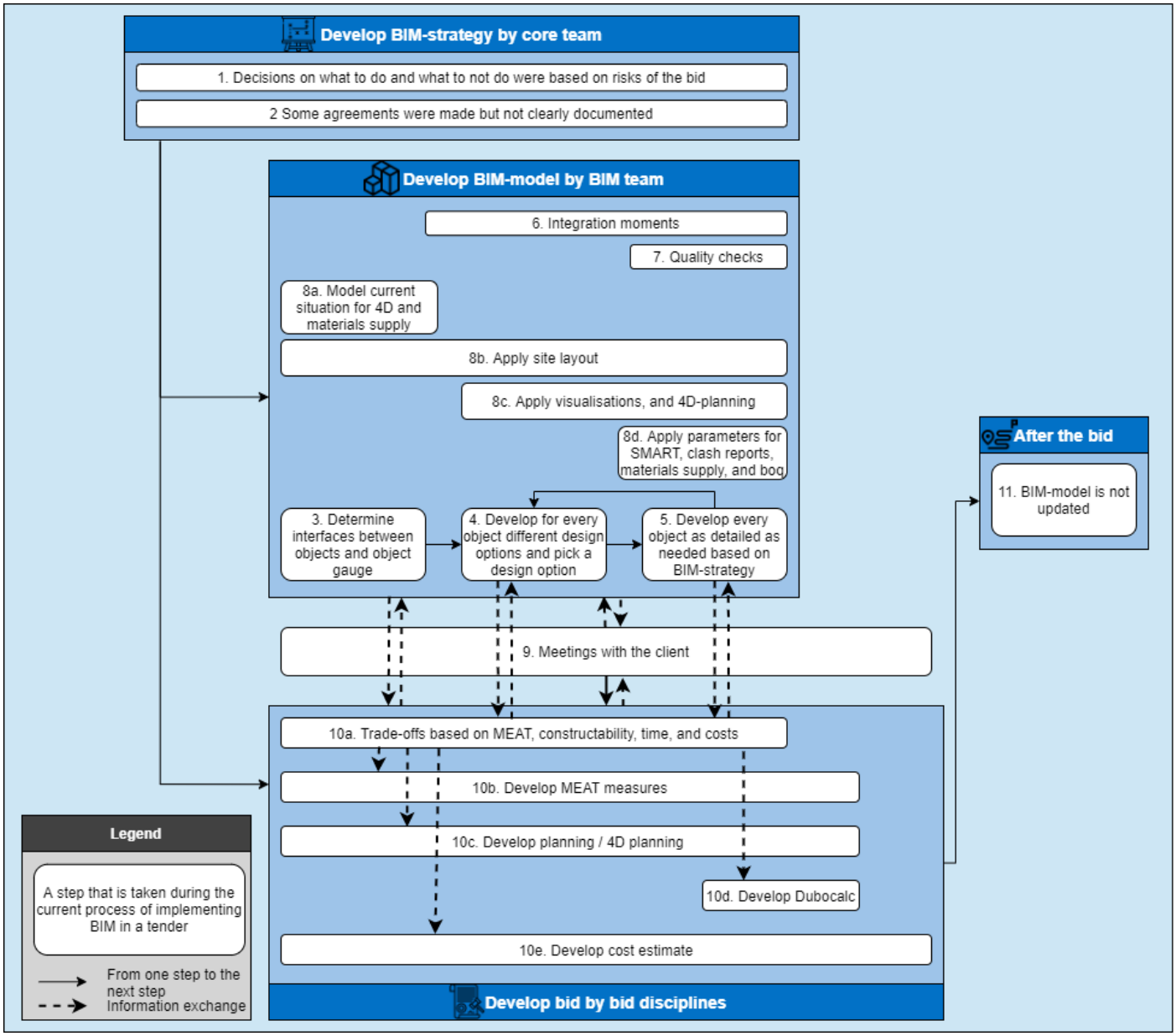

Figure 2: Current process of implementing BIM in a tender

the relationships of these roles are related to BIM in the tender. It also provided the different steps that were taken throughout the tender, split in BIM-strategy, development BIM-model, bid development, and after the bid. The different steps taken are illustrated in Figure 2. This gives an overview of what is done at this moment when applying BIM and the problems that can already be defined.

During the current process, there was a clear difference between the start of the tender (BIM-strategy), during the tender (split up into the development of the BIM-model and the development of the bid), and after the bid, like expected from literature. Although the BIM-strategy was developed before the bidding phase of the tender, many adjustments were made until the end of the tender. Moreover, they were not clearly documented and not communicated to the consortium. However, a decision was made that not everything should be modelled elaborately, which made the BIM-model specifically developed for the tender phase. The decision on which design objects should be modelled more elaborately was based on the risk of the object on the different bid aspects. The higher the risk, the more elaborate the object was designed.

During the development of the BIM-model, software was applied which was not BIM-friendly and needed extra steps to make it usable for BIM. Moreover, the coordinating software was not user-friendly and did not facilitate the needs of the consortium. One of the first steps taken during this phase was determining interfaces between the different objects. Rough designs were then made, and eventually more detailed designs were developed. During the development of the model, different BIM uses (step 8) were applied. Additional to the BIM-uses provided by literature, BIM was also used to make the MEAT criteria SMART (Specific, Measurable, Attainable, Relevant, and Time-bound) and to determine the materials supply for the construction of the

infrastructure. For the materials supply it was found that the suppliers were not able to provide enough materials for the construction, for which adjustments needed to be made in the planning. So, these BIM-uses are relevant for the tender. Integration moments were also applied from the moment that models were developed to provide visuals and to find clashes between the objects. Moreover, clashes between the object and the structure gauges were investigated, to determine whether the object meets the requirements set by the client. Furthermore, quality checks were done on the output of the models. However, such tasks were conducted after most models were already set and showed many discrepancies in the quantities of the models. This caused an unreliable view of the model for the consortium which was not considered as the single source of truth.

During the development of the BIM-model, meetings with the client were planned, where visualisations and/or videos of the BIM-model were used to explain the ideas of the consortium. Also, the bid was developed simultaneously, and ideas were communicated to the development of the BIM-model. In addition, trade-offs are made on the designs, based on MEAT, constructability, time, and costs. Despite the fictional discount that is provided for Dubocalc, Dubocalc is not considered during the trade-offs. Where Dubocalc calculates the sustainability of the materials used in the design. Dubocalc was developed at the end of the tender because it was needed for the bid. Dubocalc is important, due to the client wanting to know for almost all tenders how sustainable the design will be and is therefore needed in most tenders.

Because the bid should be based on a frozen design, the design-team stopped earlier. After the design was frozen, last-minute changes were made that had an impact on the design. Fortunately, some people of the design-team were still available for questions. However, after winning the tender, these last-minute design changes, from the end of the tender, took a long time to be adjusted in the BIM-model.

During the tender many steps, concerning BIM, were taken, but the process was not flawless. Nonetheless, BIM had an added value for the development of the bid. First of all, more insights on the design choices for the different bid aspects were provided. Secondly, BIM helped with the communication within the consortium on the ideas of the infrastructure. Thirdly, the visualisations and videos during the client meetings helped to communicate the ideas to the client. This caused a gain in trust from the client on the construction and design of the infrastructure. Lastly, the cost estimate was checked an additional time to see whether it was correct, so people were more conscious on the cost estimate and errors were corrected, although, there were more discrepancies in the BIM data than in the manual cost data.

Requirements	Description
Supported BIM	Apply BIM for developing a high-quality bid, but do not develop the whole design in BIM. Here, the design does not need to be perfect but sufficient to successfully develop a bid.
Clear agreements	Develop clear agreements on what will be applied in BIM at the start of the tender and should remain static during the tender.
Updates about BIM	Update consortium about the development of the BIM implementation during the tender.
Involvement disciplines	All disciplines should be involved in the decision making and the development of the bid, from the beginning of the tender to the end.
Quality model	Quality of the BIM-model should be high so it can be used as the single source of truth.
Efficiency	The process of applying BIM should be efficient, where a well-structured BIM-model and process can help with.
Update model	Update the BIM-model to the submitted bid, after the bid has been won.

Table 4: The most relevant requirements from the case-study

4.2. Requirement analysis of the content of the framework

The problems identified in the individual interviews were translated to requirements and used as input for the group discussion. During this discussion, additional advantages and flaws of the process, BIM-uses, and requirements were identified.

In Appendix D a table with an overview of all the requirements from the individual and group interview are represented. Most of the requirements relate to matters to be kept in mind during the implementation or to steps that need to be taken during the tender. Many requirements were mentioned many times and are therefore considered as the most relevant. An overview of these requirements is provided in Table 4.

The first requirement, that BIM should be used to be supportive, is important to not design everything in BIM, as the added value will not compensate for all the extra work. The clear agreements were mentioned as very relevant, due to not knowing what there was expected from BIM, during the current process. This caused many wrong assumptions on information retrieval at the end of the tender. Wrong expectations can also be solved by updating the consortium about

BIM. The involvement of the consortium can also help with this and with considering all disciplines views during decision making and will therefore enhance the decision-making process. Many problems were also mentioned about the quality of the model, where errors were found in the data of the model. This caused distrust in the BIM-model and people not wanting to use BIM. Therefore, it is important to keep the quality of the BIM-model good. Moreover, efficiency within the tender and also for applying BIM is important, due to the limited time available. Lastly, the implementation of BIM in this phase will result into a quicker start for the next phase, whenever the bid is won. However, the model should be updated when changes are made in the bid after the design-team concludes with the design. Thus, the bid and the model should match after the bid has been won.

5. Proposed framework

This chapter discusses the proposed framework, which is a result of the research and several design iterations. Additionally, the framework is updated based on the results of the validation workshop. Some definitions are defined of different terms and are provided in Appendix F to simplify the framework. Some tender specific aspects are considered through the development of the framework. First of all, due to time restrictions and the deliverables of the tender, only the design objects and BIM-uses, needed to gain more insights to develop a high-quality bid, should be modelled. The objects and elements that will be modelled will be determined in the 'BIM-strategy' component. Therefore, it is important to know what to apply in BIM and especially what not to apply. Secondly, there is significant time pressure given by the final deadline at the end of the tender and the quest to retrieve data which cannot be found in the model. Therefore, agreements on expectations of BIM and the work method should be developed at the beginning. In this way, less time is needed for gathering the right data at the end of the tender. Thirdly, the development of the design and bid during the tender calls for flexibility, due to the explorative nature of the design practices and the absence of clarity on what the client really wants during the tender. More flexibility can be safeguarded during a tender by providing a feedback loop during the development of a model. Fourthly, relatively few people are involved in a consortium during a tender, however, less communication is needed when the parties involved are closely collaborating. Fifthly, by developing many design options uncertainties with the client can be diminished and a better understanding of the client's wishes can be retrieved. Finally, the disciplines of developing MEAT-measures and Dubocalc are tender specific disciplines, which is why they are also represented in the framework.

The framework exists of four different components as is found in literature: one before the tender, two during the tender and one after the tender. These components are followed sequentially: the BIM-strategy; the BIM-model process; the bid development; and after the bid. These four components are explained in more detail and are unpacked through this framework, illustrated in Figure 3. The following paragraphs will elaborate on the different components and its belonging steps taken within the framework.

5.1. Develop BIM-strategy

Only a limited part of the development of the BIM-strategy is applied during the current state of practice. This was not clearly documented and was adjusted at the end of the project. However, the BIM-strategy is desired by many disciplines from the start of the tender, without any changes made to it during the tender. During the development of the BIM-strategy, every discipline wants to be involved. The interviews also showed that the most important thing for the BIM-strategy is to determine what will be developed in BIM to support the bid. Consequently, it should first be decided whether several objects even need to be modelled for BIM, by determining the relevance of the object for the bid. Then a decision should be made on which BIM-use will be applied and on what LOD every object should be modelled. Additionally, the case study showed that the whole consortium wants to know what they can expect from BIM. So, different steps are created to develop the BIM-strategy. Lastly, all agreements made during the BIM-strategy development session should be documented. In this section the different steps shown in Figure X will be explained into more detail.

First, the goal of the tender is determined. This can also include applying BIM during the tender. Whenever the goal is to implement BIM in the tender, the framework should be applied to determine what aspects from BIM will be applied and useful. The core-team should define specific goals for the tender project to improve the success of the bid. This step is needed to get everyone aligned on the goal of the tender on determining which aspects of BIM will be implemented.

Secondly, the parties are selected. The group discussion showed that selection of the right parties for a tender is important for the implementation of BIM. In the formation of the consortium, the experts stated that, preferably, attention should be paid to selecting parties from previous collaborations. This will save time on getting familiar with everyone's work styles, etc. However, new collaborations during every tender, with specific parties specifically selected for the project, are more common. When this is the case, then select a design party who works and has experience with BIM

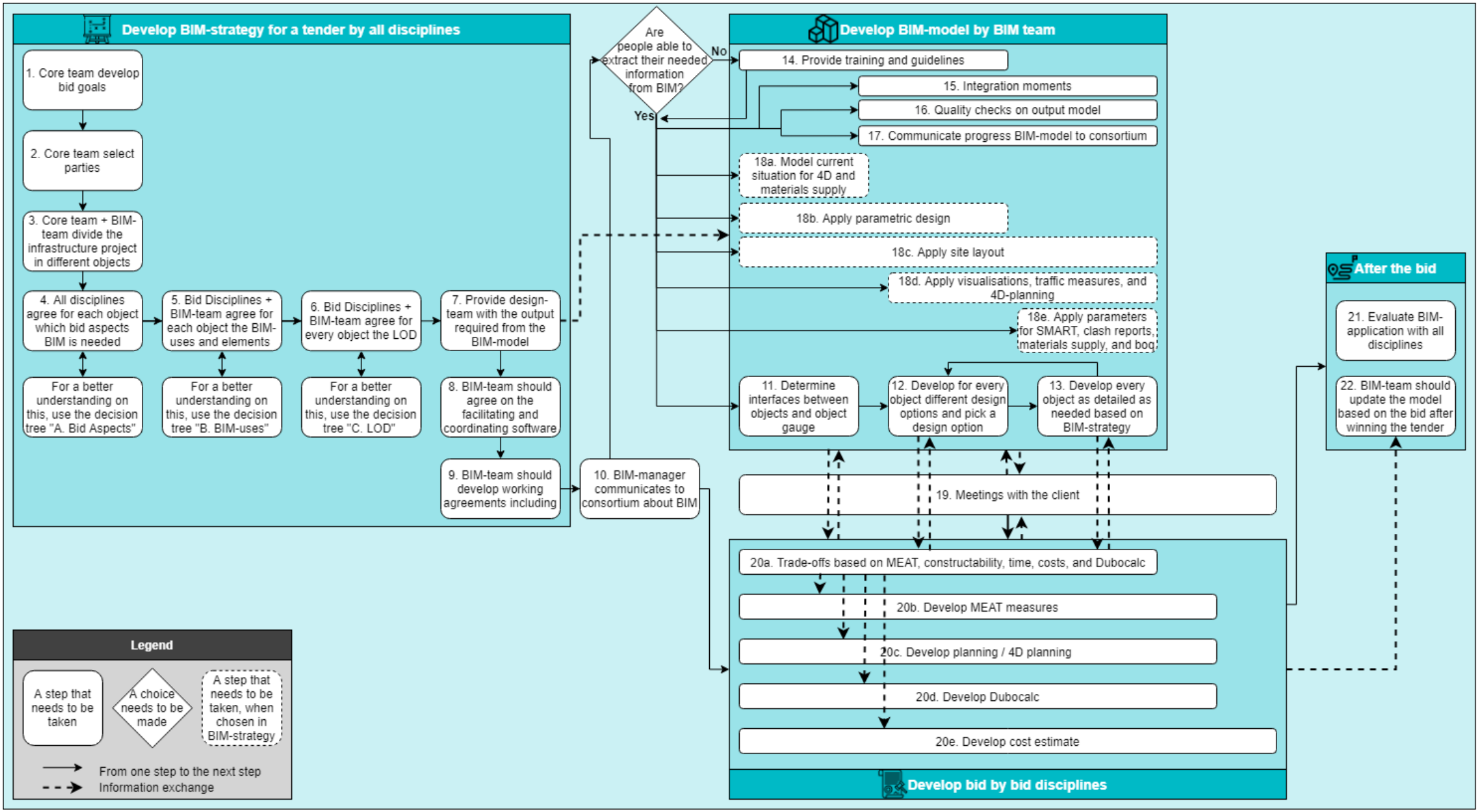

Figure 3: The proposed framework diagram

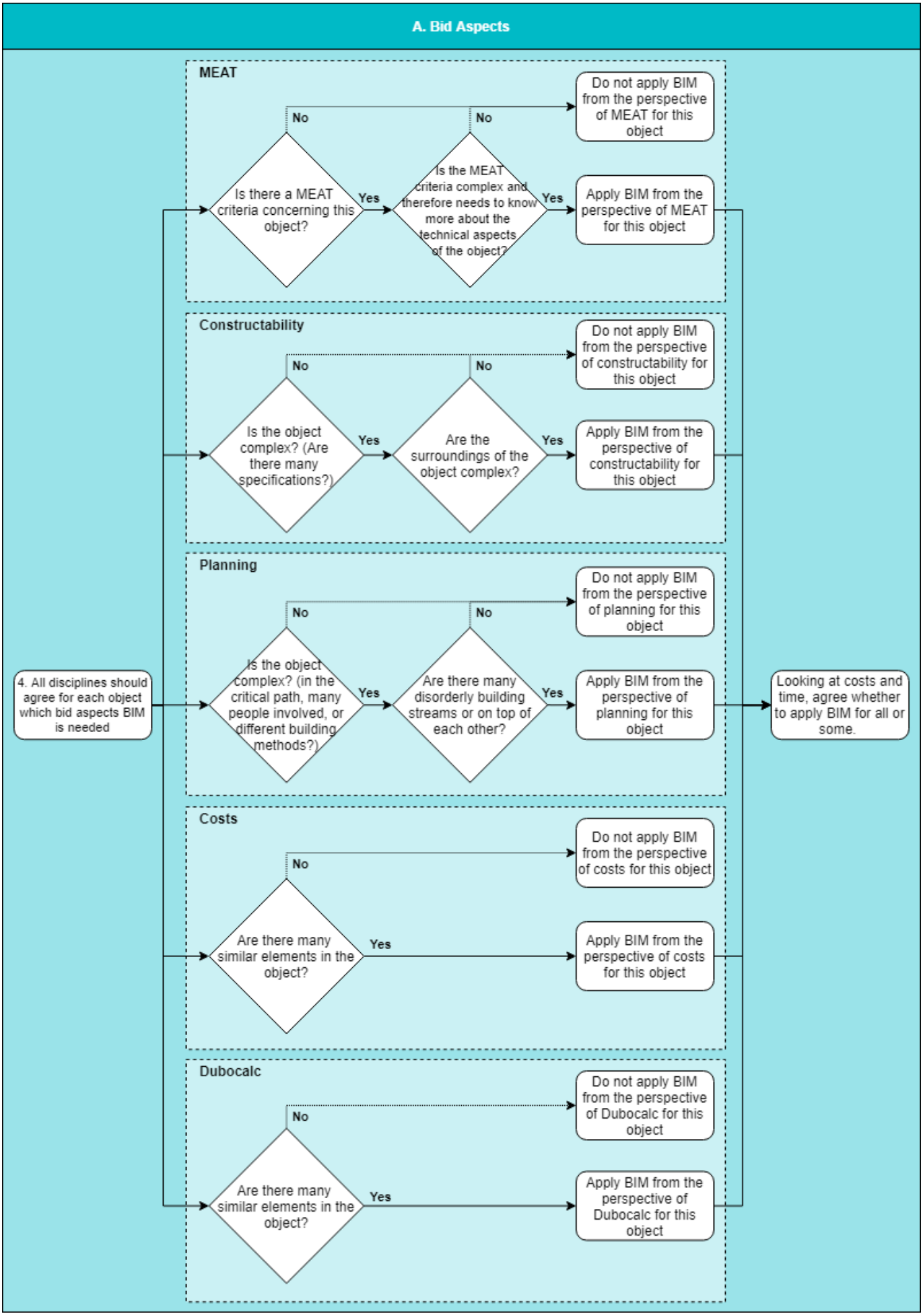

Figure 4: Decision tree "Bid Aspects"

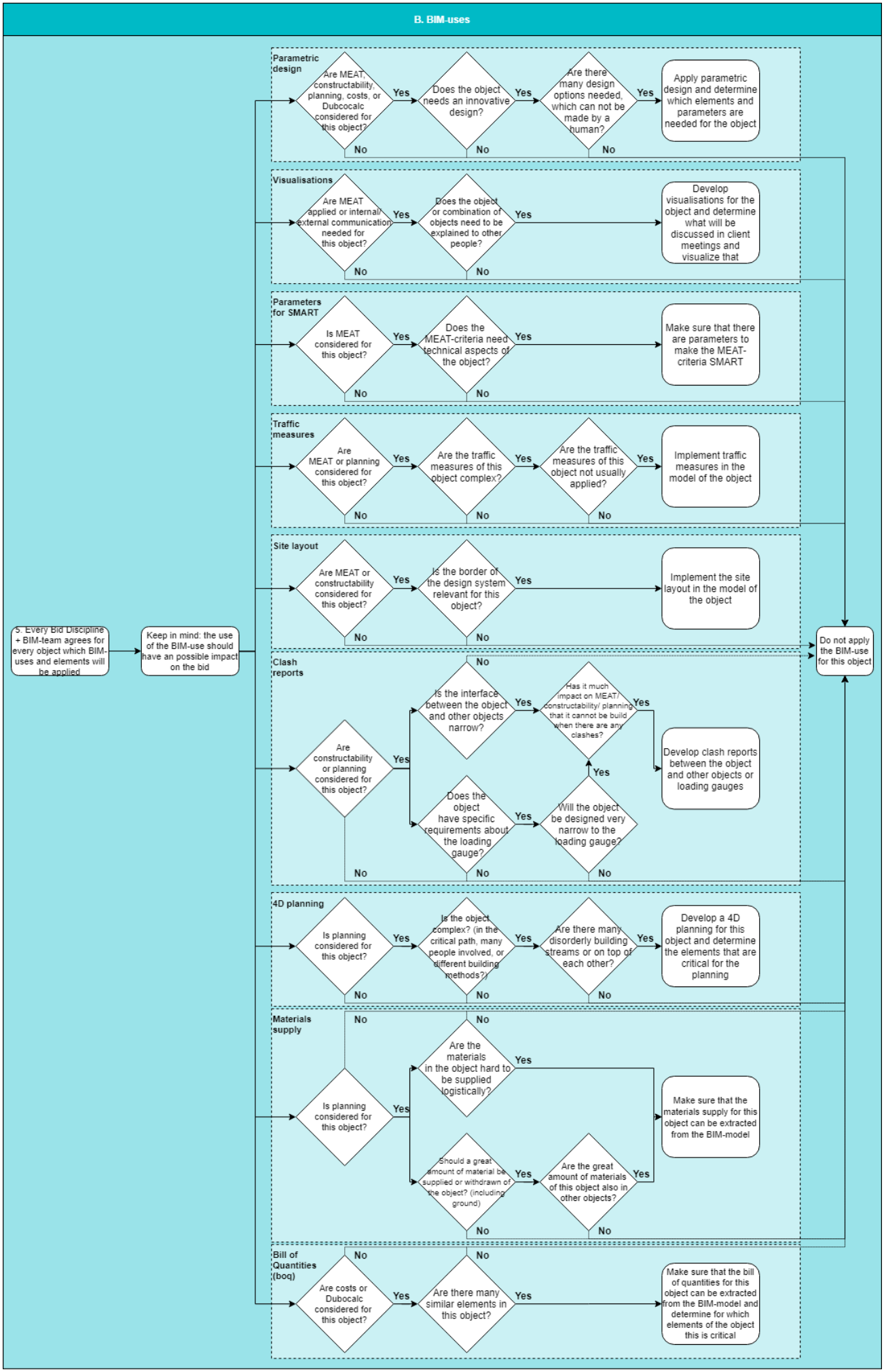

Figure 5: Decision tree "BIM-uses"

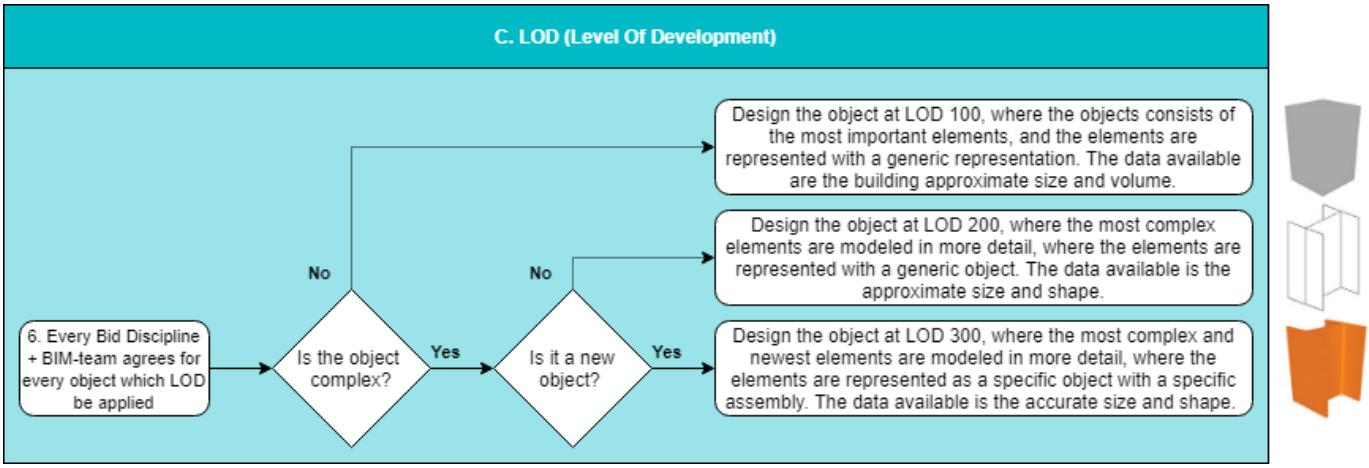

Figure 6: Decision tree "LOD"

friendly software. Additionally, the other parties that should come on board of the tender should be willing to implement BIM and preferably have experience with applying BIM.

Thirdly, in a meeting the core-team and the BIM-team divide the infrastructure in different objects and prioritize the different objects of the design in terms of their contributions to and significance for the bid. This is needed for the next steps that follow and to provide a prioritization for the bid on the design of the infrastructure. Here it is also important to include the cables and pipes within the infrastructure. Interviews told us that there is always trouble with cables and pipes within the design.

Fourthly, all disciplines decide together for each object which bid aspects will be relevant and need to be included in the BIM model. It was discussed in the group interview that it was the most important to determine which objects will be modelled for which aspect, before determining what will be applied in BIM. However, it is difficult to decide what aspects are relevant for the bid aspects. So, guidance is provided to make these decisions in the form of a decision tree in Figure 4. To keep the framework diagram as clean as possible, without adding too much information in the diagram, the decision tree provides all the information necessary for this step. This is done, because the validation showed that the first framework was hard to comprehend in a short amount of time. This was also due to the many arrows in the first BIM-strategy. Therefore, the current framework includes as much information as possible in the decision trees.

The decision tree “Bid Aspects” and the steps inside it is developed to address the requirement of first needing to know what is needed at the end of the tender from the BIM-model to support the bid. These decisions should be based on determining the different risks, which is made more specific by the different questions within the decision tree. This decision tree starts with step four from the framework diagram.

Then the disciplines answer the questions of every branch for each object. Where every branch represents one of the five bid aspects (MEAT, planning, costs, Dubocalc, and whether it is constructible or not) which must be handed in at the end of the tender phase. The MEAT aspect is related to the risk criteria that needs to be developed for the bid. The content of each question is based on the individual interviews and discussed in the validation to determine whether the questions are relevant for the different bid aspects. The validation showed that some questions could be interpreted differently, and some new discussion points were introduced during the validation. The decision trees are adjusted to make them more specific and applicable. The results from the decision trees are also used as input for the next step.

Fifthly, for each object and belonging bid aspects chosen in the previous steps, the BIM-team and bid disciplines decide which BIM-use might be relevant for each object. This is done to determine what is needed from BIM for the bid and to know what the consortium can expect from BIM at the end of the tender. A decision tree is developed to help to decide which BIM-use to use and to provide less information within the framework diagram, illustrated in Figure 5.

The decision tree “BIM-uses” is designed to address the requirement of knowing what is needed to support the bid. It starts with step five from the proposed framework. For determining the BIM-uses it should be kept in mind that the BIM-use should have a relevant impact on the developed bid. Then for every BIM-use a branch with several questions is developed, where the different possible BIM-uses are defined based on the literature review, the current state of practice, the group discussion, and the validation. The validation showed that clearer questions were needed in the decision trees, and better suggestions for these questions were given. The decision trees are updated accordingly. The first question of every branch is to know if some of the bid aspects are relevant to the object. Not

every BIM-use is relevant for every bid aspect, so a selection is provided for the disciplines.

In the next step, agree on how elaborate the object should be in terms of BIM. This should be done for every object and its belonging BIM-use(s). This includes the Level of Development (LOD). This information is needed for the design team to know what to model. The LOD is determined by the same people as who determined the BIM-uses and is based on a discussion where the participants agree on the information needed from each object at the end of the tender. The decision tree in Figure 6 can help with the determination of the LOD, where the different LODs are based on the classification provided by Dupuis et. al (2017) literature review.

The decision tree "LOD" is needed for the designers to know the detail and accuracy of the models they should produce, and for the bid disciplines to know what to expect at the end of the tender. It starts with step six from the proposed framework diagram. This decision tree provides two questions that need to be answered for which different LODs are defined. The LOD levels are based on reviewing the models, discussion with the experts, and the validation workshop. The experts stated that LOD 300 is the maximum LOD for a tender and that everybody has a different idea on the different levels of the LODs. Therefore, pictures and descriptions are provided to make sure that the whole consortium has the same understanding for all the LODs.

The next step is, for the bid disciplines and BIM-team, to decide what they expect of the BIM-use and to discuss what the output for the BIM-model should be. Based on this, the design team can develop a model that will provide the right output for every bid discipline. The interviews showed that this is crucial for fostering the involvement and for the creation of the right expectations.

The case study showed problems with the software, such as not being user-friendly and creating errors, that should not be there. Therefore, it is relevant for the BIM-team to agree on the facilitating and coordinating software that will be used and to determine the software needed for the chosen BIM-uses and design. It is helpful if the chosen software is already applied by different disciplines in the consortium in other projects. This is due to the time pressure of the tender, where there is limited time to start learning about a new system. However, when not used before software is applied, it is important to ensure that one person or a group of people are invested in setting up the system at the beginning of the tender so the software can immediately be applied when it is needed. It might be the case that the design team works with software that is not BIM-friendly. Then, the BIM-team should determine whether the software is needed to translate the models to BIM-friendly software and whether it is useful to have some elements in BIM or not.

For step nine, working agreements about the practice of BIM are created to establish the same working methods and expectations for every discipline involved. These can be based on a BIM execution plan or BIM-protocols and should be constructed along with the BIM-manager, the design team, and especially the modelers of the 3D-models. The working agreements should include the structure of the model. Common object structures that can be used are WBS, SBS, NL-SfB, etc. The structure of the models should also be applied during the development of all bidding documents, like the cost, planning, etc.. It seemed that this was not the case during the current process. This made it difficult to compare the various bidding documents with the BIM-model. The working agreements should also elaborate on build-up model; responsibilities per discipline; a tender planning (including phase outcomes, deliverables, and it's belonging milestones); frequency of updating models; content of dialogues and specialist meetings and the belonging expectations for BIM; the same kind of file naming; reference points; colors and identification for the object; and compatible file formats.

In the following step, the whole consortium will be updated on the BIM-strategy. The BIM-manager should communicate to the organization what will be done with BIM, what the benefits will be, what each party can get out of this, and give an example of another project to provide a concrete idea on what BIM will look like and convince people to use it. Furthermore, the communication should include insights on what every party is doing, which parties can help each other, and what the importance is of different elements. The same should be done for the onboarding of new members of the consortium. This will enhance involvement and expectations of the consortium concerning BIM, which was needed based on the case-study.

5.2. Develop BIM-model

Two different components are executed simultaneously during the tender. The first one is the development of the BIM-model, in which the decisions made in the BIM-strategy can be applied. Here, some similarities between the current process diagram and the framework diagram can be observed because many steps in the current process were seen as great aspects of the tender. However, some steps were lacking in the process or current steps needed to be taken at an earlier stage. All the steps will be discussed into more detail in this section. Step 11, 12, and 13 are sequential and will be the lead of the development of the BIM-model. The other activities in this phase should be executed simultaneously with steps 11, 12, and 13.

It is important to make sure that the BIM-model will be the single source of truth during the development of the model. This entails that all documents made will be based on the structure of the model and that the content of the model will be acknowledged as the truth. The BIM-environment should be updated every week with the latest design and decisions made. Furthermore, the BIM-model should be integrated with the different bid aspects where all relevant information can be found in one place.

The first step in the development of the model, step 11, is to determine interfaces. The infrastructure is split into different objects and these objects will be modelled separately. Due to the scale and size of the infrastructure, the model is too big for most computers to run. Furthermore, structure gauges for the different objects should be determined so modelers know how to build their models and what they got to consider.

In the next step, rough designs in BIM are developed, which entails that for every object the bigger elements are designed. However, parameters such as the exact location are not important in this step. This step is mostly needed to determine a design orientation. By first developing different rough design options for every object (decided in the BIM-strategy), the first choices can be made on seeing what the design will do with the costs, planning, and if it is manufacturable. This should only be done for the objects that are not developed during parametric design. The first design orientation should be chosen based on trade-off matrixes (step 20), to compare every important bid aspect for the different design options. By providing different design options to the trade-offs of step 20, better design choices can be made and will then be developed into more detail. The consortium knows what to expect and everyone can start basing their part on the design by deciding on a rough design at an early stage.

The models are developed into more detail in step 13 based on the choices on the LOD in the BIM-strategy. The most important objects should be modelled first. These are based on the BIM-strategy and are, most often, unique objects that need the most detail. Whenever more information is gathered during the development of detailed options, it might occur that the entire rough design of the object will also differ. Therefore, it might be possible to go back to step 14 during the development of detailed models. In this step, decisions also should be made based on the trade-offs of step 20.

In step 14, training and guidelines should be provided (when not everyone is able to extract information from BIM) on how to adopt BIM and retrieve information from BIM. Based on the literature review and individual interviews, this step is needed to enhance the use of BIM and to enhance the efficiency. Currently, everybody should go to the BIM-team to retrieve the correct information from the models, instead of getting the information out of the models themselves. These trainings and belonging guidelines are mostly for disciplines outside the design team and planning, who need to retrieve information from the model. The default assumption is that the design team knows how to work with 3D-modelling, assign appropriate parameters in the model, and plan base on a 4D-model. Several aspects might be relevant for the disciplines to know. However, for every discipline, a decision should be made on what type of training and guidelines are suited for them.

Step 15, 16, and 17 will iterate until the end of the modelling phase, where the integration moment is the first step in the iteration just as in the current process. During these integration moments, the design team and BIM-manager combine the different 3D-models, to retrieve an overall view of the whole infrastructure. The integration moments are for the development of the visualizations for communication and to detect clashes. These are based on the BIM-uses chosen in the BIM-strategy and on the date of the client meetings and its corresponding discussion subjects.

Additionally, quality checks are executed from the start of the development of the model instead of at the end when all models are finished. After one model is completed, the BIM-manager should always check the model on the quality of the output. This should be done for every model that is created. This is needed to keep the quality of BIM high and to ensure the quality can be trusted. This was lacking during the current process and recommended in the individual and group interviews. First, quality checks should be executed on the bill of quantities by randomly using old-school techniques. Furthermore, it should be checked whether the agreements are followed to enhance the quality and therefore maintain the trust in BIM by the consortium.

Moreover, an update on the advancement of BIM in the tender and the capabilities of the use of BIM at that moment are communicated to the consortium every month by the BIM-team. By doing this, the consortium knows what information they can get out of BIM on their own accord, instead of having to ask their colleagues. This will enhance the use of BIM, efficiency, and involvement of the whole consortium, which were the requirements from the interviews.

In step 18 the different BIM-uses, chosen in the BIM-strategy, are applied. This means that not all steps have to be executed for this step. The different options suggested in the framework diagram are based on the current process and on the group interview. However, the BIM-uses chosen will be applied during steps 11, 12, and 13 as visualized in the framework diagram. When the BIM uses 4D-planning and/or materials supply are

chosen for renovating or rebuilding infrastructure objects, step 18a. can be executed. Here, the current situation of the infrastructure should be modelled first to see the phasing of the infrastructure.

The next step is to have meetings with the client. These are held during the whole tender and split up into dialogues, specialist meetings, and, sometimes, a design workshop. The input for these moments is the different bid aspects and the approach of the construction of the infrastructure. The BIM-model can be shown to support the communication of the bid aspects to the client. However, working with a live model does not work in practice. Therefore, it was recommended by the experts to think of what to show to the client and prepare videos or visualizations which will be useful for the client meeting. Additionally, when the meetings with the client are over, conclusions from the meetings should be communicated back to the development of the model and bid. It is recommended to only communicate the conclusions that affect the work of the discipline.

5.3. Develop bid

The development of the bid is based on information from the BIM-model and the client meetings. It provides information for these aspects as well as it occurs simultaneously to the development of the model. This phase consists of different bid aspects and making trade-offs based on the different designs and bid aspects. Furthermore, the development of the bid is the same as the current process because this was assessed as strong. However, the development of Dubocalc is the exception. In the current process Dubocalc was not used during the trade-offs and only made as an end product. However, the case study showed that Dubocalc can have an added value to the trade-offs when it is developed from the start of the tender. The added value is provided by the fictional discount that is provided for Dubocalc to score the bid.

Information between the model and the bid should be exchanged where the bid will be based on the model. During the development of the bid, different trade-offs should be made, where the different design options will be compared, based on potential MEAT-scores, time, costs, and Dubocalc. These trade-offs are then communicated to the whole consortium so the whole consortium can base their discipline aspect on this. Additionally, the MEAT-measures, planning, Dubocalc, and cost estimate need to be developed through the tender by working simultaneously from rough to more detailed. These bid aspects all get information on the choices made in the trade-offs. Information from BIM is mostly retrieved after the rough design options are made. Moreover, by having the design stop earlier than the development of the bid, the bid can be developed based on the latest model, where there is only one single source of truth. However, when the development of the design is stopped, still some representatives of the design should stay in the consortium to answer questions asked by the other disciplines.

5.4. After the bid is submitted

After the bid is submitted, one or two more steps take place depending on whether the bid has been won or not.

When the bid has been submitted, all disciplines together with the BIM-team evaluate the BIM application. BIM literature recommends evaluations after BIM is applied to enhance the use of BIM the next time. It is also relevant to learn from applying BIM in a tender and to enhance the implementation for the next tenders. During the evaluation, the pros and cons of the models, the BIM-uses, the software, the information exchange, etc. should be discussed.

Some adjustments might have to be made to the model after the tender, based on discoveries from the bid disciplines at the end of the tender, when the design team stopped the development of the model. When the bid has been won, the BIM-model is updated immediately based on the submission. This is to enhance a quicker start-up of the construction phase, with one single source of truth: the BIM-model. In the current process this is not done, which causes a slower start for the next phase and leads to frustration by different disciplines. Therefore, this step is particularly important.

6. Results validation

The results of the validation workshop provided improvements for the framework, from which some could immediately be adjusted in the proposed framework, as explained in the previous chapter. Additionally, the five different assessment criteria were assessed. These assessment criteria are to determine whether the framework itself is usable, and to assess the most important requirements for the process of implementing BIM in a tender. Not all requirements are validated due to them being more like steps, which were immediately incorporated in the framework. While the validated requirements are more overall things of the process.

Results of the survey are shown in Appendix E and provide a clearer idea on the scores of the different assessment criteria. Keep in mind that the scores are averages of a small group of participants. To make it clearer, Table 5 summarizes the strengths and weakness of the assessment criteria, retrieved during the validation workshop.

Assessment criteria	Strengths	Weaknesses
Comprehensibility	- All steps were comprehendible - It includes the most important aspects - Helps with decision making	- The unclear questions in decision trees - Hard to comprehend in a short amount of time
Genericness	- Generic enough to apply for different projects - Framework is not prescribed but supports decision making	- More specific questions needed in decision trees - Costs of BIM are not incorporated in the decision making
Ease of use	- The framework will be used in next tender projects - Helps making multidisciplinary decisions in a short time	- Hard to explain it to the whole consortium in a short amount of time
Efficiency	- Framework will enhance efficiency - Helps with creating the right expectations for the end on what information could be retrieved from BIM - Helps modelers defend their modeling-strategy - A quick and complete start of tender	
Reliability	- Enhances collaboration and involvement of consortium - Expectations BIM will be more accurate - Supportive for BIM	

Table 5: Summary table of strengths and weaknesses validation

6.1. Comprehensibility

The framework is seen as comprehensible, where BIM-strategy is mostly considered as understandable and clear. However, during the case of the workshop, discussions started on the different questions of the decision trees. This is mostly adjusted in the proposed framework. Nonetheless, more research should be done on the decision trees, by implementing the framework in a tender, and to observe the discussions needed to form a BIM-strategy. This is needed to make the questions asked more specific and complete. Additionally, the framework was hard to comprehend in a short amount of time. The overall look and feel made the framework difficult to understand by quick glance. However, when studied for a longer time, all the steps provided in the framework were understandable. Therefore, the lay-out of the framework needs be adjusted, especially the BIM-strategy. Nonetheless, the overall look and feel to enhance the quick comprehensibility of the framework can be improved, by testing the framework with different participants where a short amount of time is provided to comprehend the framework. After this, a discussion can be held on how the framework can be enhanced. Notwithstanding, the framework includes the most important aspects, and is understandable when more time is taken. This will help the organization during the tender phase. This framework is usable, especially for making decisions.

6.2. Genericness

The genericness of the framework scored neutral. The participants did not find the framework too detailed to apply it for different projects. However, the framework is too generic at some places. To make it more comprehensible the questions of the decision trees could be more specific. This is already adjusted in the framework as stated in the comprehensibility. Notwithstanding, the framework can still be applied for different tender projects. By implementing the framework more and by executing more case studies the specification of different parts can be improved. Additionally, the decision making in the BIM-strategy does not incorporate the cost of applying BIM. This can add a great value for the decision-making process and is therefore interesting to do further research on. Nonetheless, it was stated that the framework is not prescribed but supporting for decision making, which means that the framework is not too detailed but mostly supportive. So, therefore, the framework is not too generic or too detailed but can be improved by being a bit more specific.

6.3. Ease of use

Overall, the experts think that the proposed framework is easy to use, and the framework will also be applied in tenders. The value of applying the framework and to set the goals of BIM in the tender is seen by the experts. Furthermore, the framework will also help to persuade people to apply BIM in the tender. The framework helps to make many multidisciplinary decisions in a short time and is especially useful during a kick-off session on applying BIM in a tender. It also provides looking out for the goal of the tender and to find out how BIM can be helpful for the tender not just by applying BIM, for the sake of applying BIM. Therefore, it can be concluded that the BIM-strategy component of the framework will

mostly be used at the beginning of the tender. The overall framework is mostly useful at the start of the tender to explain to the whole consortium what can be expected. Once again, it should also be mentioned here that the look and feel of the framework can be improved, which will make the framework more applicable. Nonetheless, the proposed framework includes the most important aspects, and it will help with the organization during the tender phase. This framework is usable, especially for making decisions. Therefore, the participants stated that the framework will be shown to and discussed with the BIM-managers of different companies, to apply in tenders.

6.4. Efficiency

An important requirement from the interviews, was that the process of implementing BIM during the tender should be more efficient. When this was assessed during the validation workshop, the participants mentioned that the use of the framework will enhance the efficiency of the process. Here it is stated that the framework will help to communicate to the consortium what to do and what not to do during a tender. So, everybody will have the right expectations set for the output of BIM. Having everyone on board with the right expectations is important for the efficiency because disagreements may translate into last minute changes which increases time and therefore reduces efficiency. The different steps on communicating to the consortium and including the different disciplines during the decision-making help with these expectations. Furthermore, for modelers, it will also help them to defend their modelling-strategy due to the clear BIM-strategy developed at the start of the tender. Additionally, the proposed framework will provide a quick and complete start of the tender due to the BIM-strategy and its belonging decision trees. This will help to develop ground decisions and will provide trade-offs that should be considered. The quick and complete start is mostly relevant for the time-bounded characteristic of the tender.

6.5. Reliability

The reliability of the framework is seen as good. First, the experts stated that the framework will enhance collaboration and the involvement of the whole consortium, instead of only the BIM-team. This is due to the involvement of all disciplines during the BIM-strategy, and the communication-steps along the whole framework. The involvement of the whole consortium will ensure the reliability of the framework, by making sure that all decisions are made with the different discipline's insights. Furthermore, the expectations of the parties on BIM will be more accurate. Moreover, the framework is reliable to use in a tender due to the quality checks ensured in the framework. This will improve the quality of the data of BIM and is therefore useful. Additionally, the experts also stated that BIM will now be applied to help the goal of the tender and to develop the best bid that is possible, instead of applying BIM for the sake of applying BIM. This will also make sure that the framework is reliable to the use for a tender. The use of BIM to help the goal of the tender is triggered by the way in which the BIM-strategy component is designed. So, overall, the framework will add value for the tender process considering BIM.

7. Discussions

The research contributes to the body of knowledge by providing more insight on the bidder's perspective of a tender process and especially on what to do during this process, to develop a high qualitative bid. Additionally, an overview of relevant aspects of BIM for a tender process contributes to knowing the possibilities in for a tender. From a practical view, the proposed framework will bring guidance for a quick and complete at the start of a tender, whenever practitioners want to apply BIM. This was also confirmed by the experts and there was stated that the efficiency will also be improved. Moreover, it can also be used to convince people within the consortium to apply BIM. The experts stated that they would like to implement the framework, which therefore makes it a great added value to practice.

The framework proposed is based on the opinions and experiences of the different experts and translated by the researcher and eventually validated. Therefore, it can be concluded that the results of this research are not as objective as one would wish because the sample was too small to yield significant results.

The most tender specific component of the framework is the development of the BIM-strategy. This was due to agreements being important within literature, like determining the output for BIM beforehand with all disciplines involved (Alreshidi, Mourshed, & Rezgui, 2017; AIA, 2007; Ma, Zhang, & Li, 2018). This is also applied in the development of the framework. However, there is no mention on where these agreements should be based on, other than the project goals. For a tender it is important that BIM supports the making of the bid, instead of showing the whole design. Therefore, the framework shows some clearer steps on how the agreements should be determined, especially the output of BIM. Furthermore, it is important to realize that the BIM-strategy is based on the interviews. Personal interpretation by the researcher was used to develop the BIM-strategy, especially for the development of the decision trees. The questions asked in the decision trees are based on the interviews but made more specific based on the researcher's insights. The questions from the decision

trees were elaborately discussed in the validation workshop and which confirm their validity.

In regard to the components during the tender, the development of the BIM-model and the bid, it is relevant to know that this process differs a lot for every tender project. The differences for every project are based on the content of the tender, the goals, and the BIM-strategy developed. Nonetheless, there are still some elements that are relevant for most tender projects and are therefore visualised in the framework. However, by implementing the framework and by observing different tender projects, more important similar factors can be found to make this part clearer and more specific. Especially the relation between the BIM-model development, bid development and the client meetings are not very specific in the current framework. Specification of these components might bring a more systematic structure to applying BIM in a tender. Notwithstanding, it is important to realize that the process should not be set in stone, because flexibility of the process is needed during a tender.

It should be kept in mind that the evaluation of steps after the bid is based on literature (CIC, The Computer Integrated Construction Research Program, 2010; Eastman, Teicholz, Sacks, & Liston, 2008) and also on the needs of the interviewees where the interviewees saw this research as an evaluation for the BIM implementation of the tender. Additionally, the individual step on updating the model after the bid is important for a quicker start for the next phase. This was a big dissatisfaction and therefore particularly important for the end of the tender phase.

Some things should be realised regarding the methodology used for this research. The overall method for applying a case study, which formed the basis of the framework, was the best fit. This is due to the complex and new phenomena for which new and deeper understanding was needed (Bougie, et al., 2017). Nonetheless, to enhance the validity, more cases should be studied and compared. However, more cases were not available and not feasible for the time of the project. Additionally, the same people where used for the interviews for developing the requirements. The benefits of this were, that the people were familiar with the research and did already think about the problems individually, before the group interview started. More participants should be interviewed for the group interview and the individual interview to improve the validity of the research. The use of different participants (with exception of one participant, due to time and availability) for the validation and the interviews was beneficial to increase the validity. Nonetheless, interviewing more experienced BIM-managers in tenders could have improved this research. This is because they are familiar with the framework and know the possibilities for the use of the framework the best.

8. Conclusions and future research

A framework is proposed for implementing BIM in the tender phase, to provide a more systematic process during tendering. The framework helps to determine the scope of the implementation of BIM during the tender and shows which steps, considering BIM, should be taken during the tender. This framework is based on a literature review from BIM and tendering; individual interviews with experts; a group interview; and lastly improved by validating the framework in a workshop. The framework shows different decisions that need to be made to develop a BIM-strategy, including decision trees to help make the decisions; different steps that need to be taken during the development of the BIM-model; how to develop the bid; and what to do after the bid has been handed in. Within the framework, it is most important that within the tender not everything should be applied within BIM, but decisions should be made on what will be modelled and especially what not. The decisions made should be based on what will have the most impact on developing the bid. Additionally, the framework includes different communication moments, where not only collaboration within the consortium is needed, but with the client as well. Furthermore, the quality of the model should be maintained to make sure the BIM-model is the single source of truth. The quality can be improved by making the right agreements and doing enough quality checks. Lastly, after the bid has been submitted, one (when the bid is not won) or possibly two (when the bid is won) extra steps have to be executed. These steps are important for a quicker start for the next phase and future tender projects including BIM.

It can be concluded, based on the validation, that the proposed framework is seen as comprehensible, where the most important steps for applying BIM in a tender are considered. Additionally, the framework is not too detailed so it can be applied for different infrastructure objects. However, some steps can be more specific to help with making decisions. For the ease of use of the proposed framework it is stated that it will help for a quick and complete start of the tender. Also, the experts would like to apply this framework in their next tender projects. There is mostly expected that there will be an increase in efficiency during the tender using the framework. The reliability of the framework is good, due to the early involvement of the consortium and the intension of the framework to use BIM to support the goal of the tender, instead of applying BIM for the whole design, without adding any value for the tender.

So overall, this framework adds meaning for determining the scope of BIM in the tender and the steps taken during the tender and after the bid has been handed in. This will create a quick start at the beginning of the tender in relation to BIM. Therefore, the message is to use this framework for big tender projects, with a competitive dialogue procedure, where the bid is assessed based on MEAT and when BIM is wanted to be used to support the development of the bid.

The framework is a good first step to provide a systematic approach, however, it can still be improved by doing more research. Firstly, the framework should be applied in an infrastructure tender project (preferably several infrastructure tender projects) to truly validate and improve the framework. By doing this, the questions and steps taken, could become more specific and elaborate. Especially the steps after the BIM-strategy can be more elaborate and better researched. Secondly, more research can be done on the impact of applying BIM in a tender considering costs and value to the bid aspects. Whenever these factors are known for different ways of applying BIM in a tender, even more, substantiated choices can be made during the development of the BIM-strategy. Thirdly, the look and feel of the framework can be improved. This can be done by creating several frameworks with the same content and to determine, which frameworks are comprehended the quickest. Overall, the research showed that although some minor adjustments have to be implemented, the proposed framework is functional and can be of added value at the start of a tender whenever BIM is considered.

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Appendix A – Individual interview topics

Topics components	Topics questions
Participants information	
	Job function within the tender
	Experience
Role in tender	
	Involvement in the client meetings
	Steps taken within the tender
BIM in the tender	
	Implementation of BIM
	Agreements for BIM
	BIM-model usage
	Information exchange
	Abilities for the use of BIM
Tender characteristics	
	Tender specificity
	Clients needs and wishes
	Changes within the tender
	Relationship time/money/quality (MEAT)
	Time limit

Table 6: Individual interview topics table

Appendix B – Group interview topics

Topics components	Topics questions
Problems	
	Problems in the tender
	Solutions for the problems
Good aspects	
	Strong aspects of the tender
BIM-uses relevant for tender	
	Parametric design
	4D planning
	Bill of quantities
	Site layout
	Visualisations
	Parameters for SMART

Table 7: Group interview topics table

Appendix C – Validation workshop topics

Topics components	Topics questions
Case (develop BIM-strategy)	
	Choose bid aspects
	Choose BIM-uses
	Choose LOD
Survey	
	Comprehensibility
	Genericness
	Ease of use
	Efficiency
	Reliability
Group discussion	
	Experience of the case
	Comprehensibility
	Genericness
	Ease of use
	Efficiency
	Reliability
	Improvements framework
	Strong aspects framework

Table 8: Validation workshop topics table

Appendix D – Requirements for the process of implementing BIM in a tender

	Requirement
1	The goal of a tender should be to develop a winning bid, so only develop models of the objects that have a high risk and those who have a need to get more insight for MEAT, planning or costs, so that these things can be developed properly, this due to the time pressure
2	Use a system that is friendly to use for the central information, so people will want to use it
3	Use software that works with 3D objects for modelling, so all the modelling tools can be integrated with each other
4	Minimal effort for what should be retrieved
5	Do as much as possible in the beginning of the tender, to have less work at the end of the tender
6	The consortium has to adjust fast to changes from within their own company and by the client, because specialist meetings and dialogues can change the whole dynamic, because either the client has new insights, or the consortium gets more insights.
7	There is a small design team in a tender, where only one person works in one model, and the interfaces between road and civil construction is easily discussed between discipline
8	All systems and processes should already be standing for the tender starts, because there is no time for that, caused by the high tempo in which a tender develops
9	Most ideally is that the consortium exists of people who have all worked together before, because that will save time on getting to know each other's workstyles etc.
10	Have a high ambition level on what you want to do on applying BIM and try to do it as good as possible. With a higher ambition level is gained more than with a low one.
11	BIM provides structure for the information about the project, which is needed because a tender is chaotic
12	BIM is also valuable for when the tender is won, for a quick start up
13	The process should be efficient. BIM can help to fast track this process.
14	Dialogues and meetings are important in a tender, this is the only place where their meetings with the clients can be held to discover their needs and wishes. However, a clear answer on what the client wants cannot be gained, but a feeling on what the client likes best can be retrieved
15	A tender is very dynamic, where the consortium is looking for the best design, so there is no structure
16	In a tender, the design should not be 100% perfect, but it should be good enough to gain insights in the costs, planning and MEAT
17	Make sure that everyone is informed about the BIM application in the project
18	Make connection between the coding of the planning with the coding of the objects, to provide an automate connection between planning and the 3D model
19	Coding and names should be the same between every discipline, to make sure that all the disciplines are always talking about the same thing and comparisons can be done more easily.
20	The design has to be finished one month before the qualitative part has to be hand in, to finish the last parts of MEAT, planning and costs, which is then based on one design
21	Set internal deadlines where aspects of BIM should be finished
22	When last changes in plans cannot be incorporated in the design, the design should be updated right after the project is won.
23	Implement BIM in the early stage of the tender, so BIM will become the information carrier of the project
24	Start the real BIM process, so 3D etc., after the funnel phase, otherwise the risk is too high
25	Someone should take the lead in BIM
26	There should be one place where all the information can get retrieved from in a structure way

27	Involve costs at an early meeting on what to involve in BIM and how, so they can retrieve the information they need to make their cost calculation, because more elements are needed, which are not provided in the models.
28	The model should be frozen one time to make sure that the costs have a version to work with
29	Costs and contractor should be involved in making decisions from early on in the process
30	Make sure that technical people have all the information that they need in one overview
31	From management team, people should always be aware of the implementation of BIM, and therefore stimulate their people to use it from the beginning and not expect results at the end, where they never asked for
32	A session in the beginning should be held with the whole design team on how to work in BIM
33	At the start, every discipline should look at what information they want to get from BIM and communicate this with the design team and BIM-manager
34	Do a weekly meeting where all the changes are discussed by the team leaders and update the rest of the consortium, where the newest update of the BIM-model is shown and can be talked about
35	After every client moment, discuss it with the team leaders and update the rest of the consortium
36	Everyone who will work with the data in the end, should be able to extract data from the model
37	Prove to people that working with BIM is beneficial
38	When there are changes in design, the elements that have been changed should be made clear
39	The integrated model should be cut in pieces, to make the files smaller so it can be shown on every laptop
40	Make notes when sessions are done about agreements and changes and save those somewhere central in one file.
41	Update the BIM-environment every week to make that the single source of truth and always have the last update and where everybody adds his own information, so everybody has the same knowledge about the project
42	Give the everyone an insight on the importance of all the elements, so they can keep that in mind
43	Send everyone only the information/changes made that is important for their discipline, so that everyone will be up to date for their part
44	Everyone should work on one location to enhance integral collaboration
45	Do quality checks of BIM data, to keep the quality of BIM data high and therefore maintain the trust in de BIM
46	Discuss the specialists that are important for the project and involve these specialists at an early stage in the tender
47	All design teams should be involved in quality checks, and the data needed
48	Make good agreements that are in line with the goal of the project (thinking from the end to the front) including: what is needed in the end (time, money etc.), than which objects are needed for that, what systems are you going to use for that, coding, the way of modelling, processes, coordination of it, working agreements, integration, frequency, sharing
49	The BIM plan should be defined in the beginning of the tender, and not be changed.
50	Coding's for temporary objects should be given, so this will not be calculated in the bill of quantities
51	Know beforehand what will be discussed when with the client in de specialist meetings and what is really needed from every discipline and have some people of every team worrying about the input for Dialogues and Specialist meetings while others can keep on producing.
52	For calculating the costs and Dubocalc, some extra materials should be included, to take the building loss into account
53	Visualizations can give insights in whether changes are incorporated into all disciplines
54	Connect cost and Dubocalc to BIM, so impact can easily be seen on those aspects for making decisions
55	Determine the goal of the visualization for dialogues and specialist meetings and ensure that the visual is comprehensible.

56	Only use 4D planning on the special civil designs, where it is harder to see how it will be build and to get some extra measures
57	Plan when which material is needed and how much, to see if suppliers will be able to supply the material
58	The ground balance is important for infrastructure and the quantities of BIM can help with determining the ground balance
59	Visualizing data in dashboards helps with better understanding the data
60	Bill of quantities is the most important aspect of BIM in a tender
61	Parametric design is valuable for a tender, to see as many design options as possible and to see the impact on costs, Dubocalc and time
62	Clash detection is relevant for a tender, especially for structure gauge (profiel vrije ruimte) and Cables and pipes
63	Traffic measures can be added to BIM
64	The site layout is only useful in BIM to see the systems border in relation to the design
65	Cables and pipes should be involved in BIM, because it is pretty easy and always a high risk in every tender
66	Dubocalc should be involved from the beginning of the project, so Tradeoffs can be made based on this
67	Costs and Dubocalc should work more closely together
68	Road design should be frozen, because the de civil design is based on this.
69	BIM is valuable for MEAT, because better decisions can be made because the impact of planning and price could be seen and to make the measures SMART.

Table 9: Requirements list

Appendix E – Graphs of the survey of the assessment criteria from the validation workshop

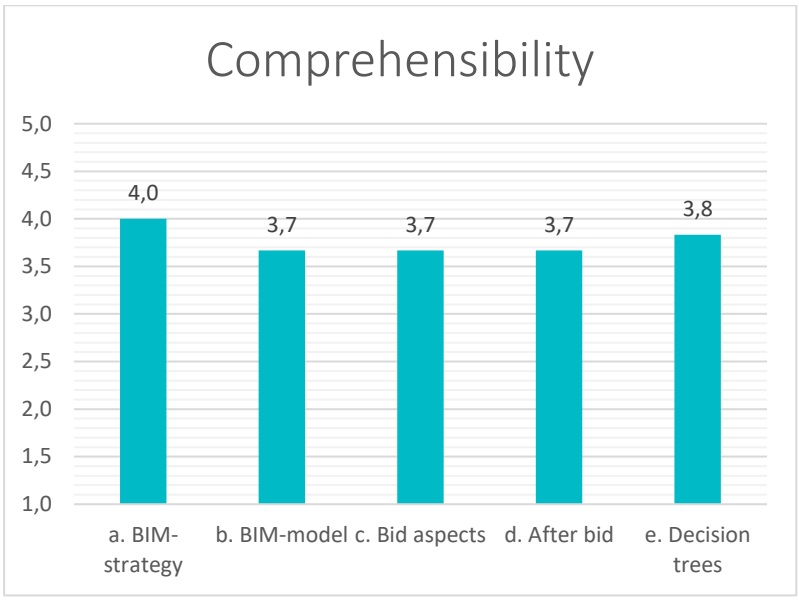

Figure 7: Validation scores of comprehensibility

Figure 8: Validation scores of genericness

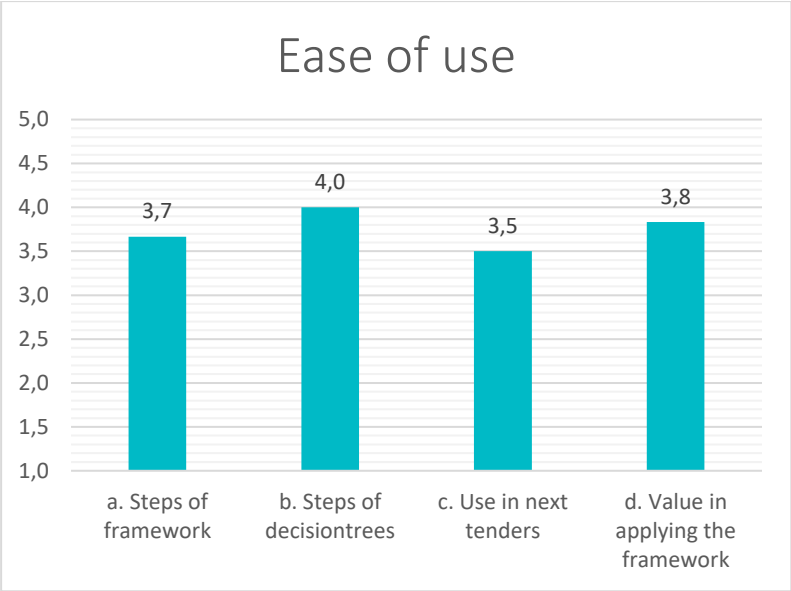

Figure 9: Validation scores of ease of use

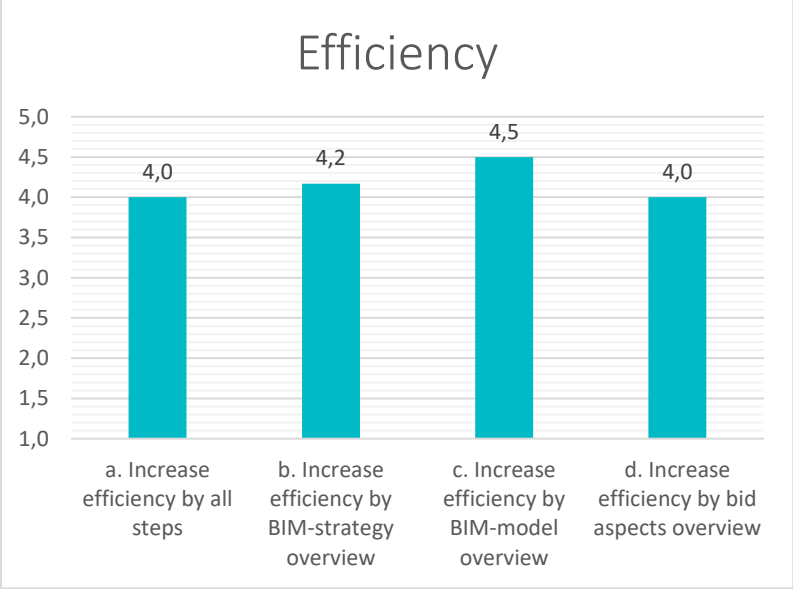

Figure 10: Validation scores of efficiency

Appendix F – Definitions framework overview

Bid Aspects
The aspects that have to be handed in at the end of the tender, including: MEAT, constructability (whether it is constructible or not), planning, costs, Dubocalc.

Bid Disciplines
The disciplines who work on the Bid Aspects.

Bid Goals
The goals that the consortium wants to achieve at the end of the tender.

BIM-uses
The different elements of BIM that can be applied.

BIM-team
The BIM-manager, BIM-coordinator(s) and the modellers who are developing the models.

Core-team
The people who have the end responsibilities and make sure that all the different tender aspects are aligned.

Elements
The different components that form the Objects, e.g., poles, bridge deck, rails etc.

Objects
A bigger part of the infrastructure like a road, viaduct, bridge, railway, sound barrier etc. and consists of different Elements.

Requirements
The Requirements set by the client.