# SE, BIM AND MBSE FOR INTEGRATED CONTRACTS

Master thesis: SE, BIM and MBSE for integrated contracts

Name: Place: Date: Version:	ing. V. Jongman Hengelo 26-05-2017 Final version
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# SE, BIM AND MBSE FOR INTEGRATED CONTRACTS

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**Abstract:** Despite the fact that traditional forms of procurement still dominate the Netherlands, the choice for integrated contracts is becoming increasingly popular. This trend is also visible at the professional contractor Dura Vermeer Bouw Hengelo (DVBH). Therefore, DVBH wants to focus more on these contracts. However, when opting for integrated contracts, DVBH must develop both the design and an accurate tender price in the tender phase of a project. They also have to meet the contractual terms of the integrated contract, such as quality assurance. However, DVBH experiences that the available time in the tender phase is limited and the tender budgets are tight, so it is difficult to make both a design and an accurate tender price within time and budget. This paper describes how a combination of Systems Engineering (SE), Building Information Modeling (BIM) and Model Based Systems Engineering (MBSE) can be used to develop a design and calculate an accurate tender price within the limited time range. In addition, it is investigated to which extent this combination is applied at DVBH and can be implemented. It can be concluded that, according to literature, (1) an integral model must be developed that (2) represents an appropriate solution that complies with both the (3) requirements and (4) limiting information. However, this combination is only partly applied at DVBH, mostly due to a lack of time, knowledge and suitable ICT resources. Interventions, such as a more efficient division of time and investments in knowledge and ICT resources are needed to implement the combination at DVBH.

Keywords: systems engineering (SE), building information modelling (BIM), model based systems engineering (MBSE), integrated contracts (UAC-IC)

The construction branch is dominated by traditional forms of procurement, where the design and construction phases are contracted out to other parties (CROW, 2016). But several factors, such as the lack of integration and effective communication, uncertainty, changing expectations of the client, complexity and a changing environment result in the choice of alternative forms (Naoum & Egbu, 2015). One of these forms is the integrated contract (UAC-IC, or Uniform Administrative Conditions for Integrated Contracts (Chao-Duivis, Koning, & Ubink, 2013)). In this contract the design and construction phases, and possible other phases like maintenance finance and operations are carried out by one party: the contractor (Wentzel, van Eekelen, Bone, Rip, & Bone, 2011). This means that the contractor is responsible for these phases. Besides this, important contractual conditions apply to the integrated contract. At first, the contractor is obliged to carry out the work according to the requirements in the contract (art. §1 section 1 UAC-IC 2005) and has to prove that the product meets these requirement by means of a quality assurance test (art. §19 UAC-IC 2005). Secondly, the contractor must take into account the condition of the soil (art. §13 UAC-IC 2005) and is responsible for the (financial) effects when the condition of the soil has not been taken into account. At last, in an integrated contract the tender price is fixed. This means that, after awarding the project to the contractor, the tender price cannot simply be changed and the contractor is responsible for the costs that arise when the tender price is estimated too low (de Ridder, 1994; Goossens, 2004).

These new responsibilities and conditions ask for a new way of working. The contractor has to take the initiative in the process, has to listen more carefully to the customer and has to work in a more structured way (Kuijpers & Post, 2014). In literature a combination of Systems Engineering (SE) and Building Information Modelling (BIM) is proposed to do this (van Eck, 2016; Spekkink & Savanovic, 2013). *"Systems Engineering is used to capture the requirements and interfaces in a structured way. BIM can be used to visualize the solution and to unlock the information in an integrated model. This model can be used to verify the requirements (van Eck, 2016)"*. The availability of literature about the combination is scarce, but some papers speculate about the use of Model Based Systems Engineering (MBSE) (Valdes, 2016; Geyer, 2012; Robert, Delinchant, Hilaire, & Tanguy, 2013). This method helps to verify requirements by means of a BIM model and can therefore be beneficial for integrated contracts. In this paper the application of a combination of SE, BIM and MBSE for an UAC-IC project is examined.

# 1. Introduction

The increasing popularity of UAC-IC contracts is also visible at Dura Vermeer Bouw Hengelo (DVBH): a division of Dura Vermeer, one of the largest professional builders in the Netherlands. The organisation's strategy is to focus more on UAC-IC contracts (Dura Vermeer Bouw Hengelo BV, 2016). But DVBH is confronted with some challenges. First, they have to make a preliminary design that meets the requirements of the client and they have to calculate an accurate tender price, all in a short period of time (3-16 weeks). Secondly, the tender budgets are tight, resulting in a limited capacity that cannot simply be increased. Because of this, DVBH experiences difficulties delivering a design and an accurate tender price within the available time and budget. For example, DVBH can overlook requirements that may have a big impact on the tender price, resulting in additional costs. DVBH thinks that SE and BIM can help to include all the requirements and to calculate an accurate tender price. They however do not know how and are curious how a combination of SE and BIM can help to increase the accuracy of the tender price.

MBSE is added as an extra factor in this paper, because it can be a possible combination of SE and BIM according to literature. MBSE can be beneficial for UAC-IC projects, because a combination of SE and BIM can help to verify requirements quickly based on a 3D-model. Therefore, this paper focuses on the combination of SE, BIM and MBSE. The goal is to make recommendations to DVBH for applying a combination of SE, BIM and MBSE for UAC-IC projects to improve the accuracy of the tender price. The main question of this paper is: "to which extent can a combination of SE, BIM and MBSE be applied to improve the accuracy of the tender price for UAC-IC projects at DVBH?"

However, after a Quick Scan of existing literature it became clear that no suitable tools could be found to measure accuracy. In general, accuracy can be measured by calculating the difference between the budgeted costs and the actual costs. But this difference is highly influenced by changes. These changes include (I) changes in the contract, (II) optimization of the design to save costs and (III) reservations for risks. However, more changes does not mean that the accuracy is low and a low amount of changes does not mean accuracy is high (Albrecht, 2015). In literature, no methods could be found to determine the accuracy of the tender price including the effect of the changes. Thorough research is needed to find a suitable way to measure accuracy taking into account the changes and possible other variables that can affect the tender price at DVBH. This is not possible within the scope of this research. Because of this, the main question is limited to the application of SE, BIM and MBSE activities, which can improve accuracy according to literature, at DVBH. Also, this paper looks at the implementation of the activities at DVBH. However, this implementation has not been investigated scientifically. It provides guidelines for DVBH for further implementation. The main question in this paper is therefore: "(I) to which extent is a combination of SE, BIM and MBSE activities -that can improve the accuracy of the tender price of an UAC-IC project according to literature- applied at DVBH and (II) to which extent can these activities be implemented at DVBH?" The first part of the question is the scientific part of the paper and the second part of the question has not been scientifically investigated.

So, in this paper the (careful) assumption is made that the SE, BIM and MBSE activities can improve accuracy. Further research is needed to prove this. Also, the scope of this paper is limited to the tender phase, because the tender price is made in this phase and the limited time and budget apply to the tender phase. Also, DVBH experiences difficulties in this phase. The main question of this research can be divided in three sub-questions:

- **Sub-question 1**: Which combination of SE, BIM and MBSE activities can be applied to improve the accuracy of the tender price for an UAC-IC project according to literature?
- **Sub-question 2**: To which extent is the combination of SE, BIM and MBSE activities -that can improve the accuracy of the tender price of an UAC-IC project according to literature- applied at DVBH?
- **Sub-question 3**: To which extent can the combination of SE, BIM and MBSE activities -that can improve the accuracy of the tender price of an UAC-IC project according to literature- be implemented at DVBH?

# 2. Method

To be able to answer the main question, this paper is divided in three parts, corresponding with the three subquestions, namely: (1) the conceptual model, (2) the current situation and confrontation and (3) the implementation proposal, see Figure 1 Research model.



#### FIGURE 1 RESEARCH MODEL

In the **first part** of this paper a conceptual model will be developed, describing the combination of SE, BIM and MBSE activities that can improve the accuracy of the tender price of an UAC-IC project (sub-question 1). Literature research will be conducted on four subjects: (I) *Systems Engineering* (SE), (II) *Building Information Modelling* (BIM), (III) *Model Based Systems Engineering* (MBSE) and (IV) *integrated contracts* (UAC-IC). The theory will be combined in a conceptual model that consists of a graphical scheme that explains the combination of SE, BIM and MBSE and a table with the activities needed to improve the accuracy of the tender price. These activities are described as an (expected) pattern using "*pattern matching*." Pattern matching is comparing two patterns in order to determine whether they match or not (Hak & Dul, 2009). The first pattern is the expected pattern, which is in this paper the combination of SE, BIM and MBSE activities according to literature (part 1). The second pattern is the observed pattern, which are the results of the analysis of the current situation (part 2). The (expected) pattern will be described as: *A results in B via mechanism C with condition(s) X.* "A" describes the activity and "B" the result of applying this activity. In this case the result is "an improved accuracy of the tender price". "C" is the mechanism that describes how the application of the activity results in an improved accuracy. The conditions (X) describe what is necessary to apply the activity.

The conceptual model can be used to examine the current situation of DVBH. This will be done in the **second part**. In this part the application of the combination of SE, BIM and MBSE activities according to the pattern described in the conceptual model will be investigated (sub-question 2). The data will be collected by means of a *single embedded case study*. In this type of case study the researcher tries to state something about a single case, but examines different embedded units to support his/her statement (Yin, 2003). In this paper the case is the organisation of DVBH for UAC-IC projects and different projects (units) will be examined to say something about the application of the combination of SE, BIM and MBSE activities and why they are applied or not applied. The projects are selected based on three selection criteria: (I) *type of contract* (Design & Build, Engineering & Build or Design, Build & Maintain), (II) *type of client* (public or private client), and (III) *application of SE and/or BIM*. A description of the projects can be found in Table 1 Description projects.

The case study can be divided into two parts: the *within-case analysis* and the *cross-case analysis*. In the first part the application of the SE, BIM and MBSE activities per project is being examined. In the second part the similarities and differences between the projects are being examined and to which extent the activities are applied or not applied at DVBH. The data will be collected by means of semi structured interviews. Each

interview has the same questions about to which extent the activities are applied or not and why they are applied or not applied. The following roles are interviewed: (I) *the calculator*, (II) *the tender manager*, (III) *the BIM-engineer*, (IV) *the supply chain manager* and (if applicable) (V) *the systems engineer*.

Based on the conclusions of the second part and literature about implementation theory will be determined to which extent the activities, which are not yet or not sufficiently applied at DVBH, can be implemented at DVBH. This is the **third part** of this paper: the implementation proposal. The activities that are already applied in an accurate way at DVBH will not be further studied. Besides this, possible interventions that can facilitate implementation will be discussed. The third part of this paper has not been investigated in-depth and has not been validated scientifically, but can provide DVBH with guidelines for further implementation. This is because thorough research is needed to develop a tailored implementation plan and framework for DVBH, which goes beyond the scope of this paper.

**TABLE 1 DESCRIPTION PROJECTS** 

Project	Description
Theater Wereld van	Goal: the creation of a new theatre in Emmen, which is replacing the old theatre, and a new
Ontmoeting	entrance to the zoo (Wildlands)
(WvO)	Client: Municipality of Emmen
	Contract type: Engineer & Build with Best Value Procurement
	Application SE/BIM: BIM, no SE
C-SMART	Goal: the development of a training centre for maritime training (10,000 m2) to replace the
	old one and a hotel (12,450 m2)
	Client: Carnival
	Contract type: Design & Build (training centre), Engineer & Build (hotel)
	Application SE/BIM: BIM, no SE
R&D Centre Unilever	Goal: the development of a state-of-the-art Research and Development centre for Unilever
(Unilever)	Client: Unilever
	Contract type: Design, Build & Maintain
	Application SE/BIM: SE (pilot), no BIM (yet)
Landelijk Opslag Archief	Goal: the renovation of the former government building of the Topographic Service into an
(LOA)	archive space (10,000 m2) and an office (2.200 m2)
	Client: Rijksgebouwendienst
	Contract type: Design & Build
	Application SE/BIM: SE and BIM

# 3. Part 1: SE, BIM and MBSE for UAC-IC projects

In the first part of this paper the combination of SE, BIM and MBSE activities that can improve the accuracy of the tender price of an UAC-IC project according to literature will be described (sub-question 1).

**Sub-question 1**: Which combination of SE, BIM and MBSE activities can be applied to improve the accuracy of the tender price for an UAC-IC project according to literature?

First, (1) the combination of SE, BIM and MBSE will be described in a conceptual scheme. After this (2) the activities needed to improve the accuracy of the tender price will be discussed. These activities will be presented in a table, which describes how the activity can improve the accuracy of the tender price. Per activity the pattern is described as: *A results in B via mechanism C with condition(s) X.* "A" describes the activity and "B" the result of applying this activity. In this case the result is "an improved accuracy of the tender price". "C" is the mechanism that describes how the application of the activity results in an improved accuracy. The conditions (X) describe what is necessary to apply the activity, for example ICT-resources, skills or other SE, BIM or MBSE activities. Finally, (3) the value and limitations of the combination will be discussed. The end product of this chapter is a table that can be used to examine the current situation at DVBH, see Table 2 Method Part 1.

TABLE 2 METHOD PART 1

PART 1: CONCEPTUAL MODEL				
Activity Expected pattern Impact/improvements				
Activity X.	A results in B via mechanism C with	Improvement accuracy and possible		
	condition(s) X.	other improvements		

# 3.1. The combination of SE, BIM and MBSE

To be able to calculate an accurate tender price literature proposes the use of an integral model for calculation (Ghaffarianhoseini, et al., 2016). When using the model, a price can be calculated with a bias as low as 3%. This means that the difference between the budgeted and actual costs is +/-3%. According to Bredehoeft (2012) a bias between -5% and +15% is minimally required for calculating a tender price (Bredehoeft, 2012). So, if the model is used for the calculation this bias can be achieved. However, there are certain elements needed to develop the model and run the calculation for UAC-IC projects. These elements represent different kinds of information needed (Baker, et al., 2000) which are stored in containers. These containers are:

- 1. **Model**: there must be an (integral) model that gives a good reflection of reality (Valdes, 2016; Baker, et al., 2000);
- 2. **Solution**: the model must be a representation of a solution that fits the scope, the requirements and expectations of the client (Valdes, 2016; Baker, et al., 2000);
- 3. **Requirements**: to be able to develop a model that gives a good reflection of reality, both the solution and the model need to meet the requirements of the client (Valdes, 2016; Baker, et al., 2000). This is also mandatory according to the UAC-IC (art. §1 section 1 UAC-IC 2005);
- 4. **Information**: to be able to develop a model that gives a good reflection of reality, both the solution and the model need to fit the scope, regulations and other specifications/information (Valdes, 2016). Information is not the same as requirements. Information facilitates while a requirement confines. However, requirements may arise from information.

In order to meet these conditions, a combination of SE, BIM and MBSE can help. The tender price must be determined based on an integral model that meets the requirements and specifications/information (Valdes, 2016; Baker, et al., 2000). This means the model must be verified. MBSE is a method in which the model is used to verify whether the requirements are met (Valdes, 2016; Baker, et al., 2000). For this verification process, a SE database and a BIM database must be developed, and they need to communicate with each other by means of a standardized computer language, like OML SysML (OMG SysML). The SE database contains information about the requirements and specifications/information (Valdes, 2016). In order to develop this SE database, Systems Engineering activities are required to transform customer demand into clear specifications, and specifications into a suitable design (Department of Defense, 2001). The BIM database contains a 3D-model of the product, including necessary information, such as materials, equipment and time-information (Polit-Casillas & Howe, 2013). Various BIM activities are required to develop the model. By comparing the information from the SE database with the information in the BIM database, one can determine whether the product meets the requirements and specifications/information (Valdes, 2016; Baker, et al., 2000). MBSE activities are needed for this process. MBSE is required for the link between the databases and for the correct computer language. Also MBSE is needed for the exchange and comparison of information. When the developed model meets the requirements and specifications/information, it can be used for the calculation of the costs (Ghaffarianhoseini, et al., 2016).

The combination of SE, BIM and MBSE can be graphically displayed in a conceptual scheme, see Figure 2 Scheme conceptual model. This abstract conceptual scheme is based on the theory of Baker et al (2000) and Valdes et al (2016). In this diagram, the four containers required to determine an accurate tender price are present, namely (1) the model, (2) the solution, (3) the requirements and (4) the information. The arrows between the containers indicate the relationship between the containers: the model calculates (whether or not automatically) a tender price (Ghaffarianhoseini, et al., 2016). The model is a graphical representation of a chosen suitable solution. This solution informs what the model should look like (Valdes, 2016; Baker, et al., 2000). In addition, the model must fulfill the requirements (Valdes, 2016; Baker, et al., 2000). Also, the model uses information, such as policies and regulations or material-specific information (Valdes, 2016). The solution itself should *fulfill* the requirements (Valdes, 2016; Baker, et al., 2000) and also uses information (Valdes, 2016). There is also a reverse relationship between the solution and the information and the solution and the requirements (Valdes, 2016; Baker, et al., 2000). The requirements specify the solution and certain information restrict the solution (Valdes, 2016). The relationship between "requirements and information" is not described by Valdes (2016) and Baker (2000). However, requirements may arise from information, such as policies and regulations or information about the scope and the stakeholders (Department of Defense, 2001). Because this relationship is not clearly described in literature, the arrows in the scheme are grayed out.



FIGURE 2 SCHEME CONCEPTUAL MODEL

A: Activity

# 3.2. Activities

To be able to develop a model that meets the requirements and other specifications/information that can be used for the calculation, different SE, BIM and MBSE activities are required. In the scheme, see Figure 2 Scheme conceptual model, these activities are displayed per container (model, solution, requirements and information). In this chapter these activities will be discussed. For each activity, the pattern (*A results in B via mechanism C*) will be described. Also the conditions (X) that are needed for the application of the activity will be discussed. The activities are summarized in Appendix 1. SE, BIM and MBSE.

# Activity 1.1. Calculation based on the model

The goal of the combination of SE, BIM and MBSE is to determine an accurate tender price. According to Ghaffarianhoseini et al (2016) the model can be used to calculate an accurate price. A model is more accurate than 2D drawings, which makes the calculation of the tender price more accurate. A price with a bias as low as +/-3% can be calculated (Ghaffarianhoseini, et al., 2016). This is done by extracting quantities of materials, time or personnel from the model and multiplying it with actual price information (Peterson, Fischer, & Tutti, 2009). By doing this the calculation time can be reduced (Autodesk, 2007). The following conditions (X) apply:

- LOD300: in order to achieve the bias as low as +/-3%, the model must contain as much information as possible. For a tender price, information based on units is required (Bredehoeft, 2012). This means that the individual objects must be modelled and information can be extracted from these objects. Therefore, the elements in the model must be worked out to (at least) LOD300 level (BIM Forum, 2016). LOD, or Level of Development, is "the extent to which the geometry of an object and its associated information has been devised (BIM Forum, 2016)". LOD300 means that the elements (objects) in the model are specific and the quantities of the objects are measurable (BIM Forum, 2016). To do this, Activity 1.4 Integral 3D Modelling is required;
- 2. **Model with 4D-information**: in order to calculate labour and material costs, information about labour, equipment and planning (4D information) is required and must be added to the model (Zhang & Hu, 2011). Activity 1.5. Building flow simulation is needed to develop a 4D-model with 4D information;
- 3. **Meet requirements and specification/information**: the model should give a good reflection of reality and should therefore meet the requirements and other information/specifications (Valdes, 2016; Baker, et al., 2000). A model that does not meet the requirements has to be adjusted (in a later stage), which may result in a bigger bias and therefore reduced accuracy. To avoid this, the model must be verified and validated before the calculation is conducted. Activity 1.2. Verification and Validation is needed to verify and validate the information.
- 4. **Consistent integral model**: the model must reflect one truth and must provide clear and actual information. This means that all information, added by all disciplines, must be stored in one consistent integral model (Valdes, 2016). Activity 1.3. Conflict control is needed to check if the model is consistent and the information does not conflict with each other;
- 5. Actual price information: one must use actual price information for the calculation (Liu & Zhu, 2007). Incorrect price information can result in deviations and a reduced accuracy. Activity 4.1. Link with price database can be used to link the model with a price database;
- 6. **ICT resources**: there must be suitable ICT resources for the (automatic) calculation available (Valdes, 2016);
- 7. **Skills**: there must be appropriate skills available to be able to work with the ICT resources and to conduct the calculation based on the model (Valdes, 2016).

# Activity 1.2. Verification and validation (V&V) of the model

In case of an UAC-IC project it is important that the contractor can prove compliance with the requirements (art. §19 UAC-IC 2005). Verification and validation can help to do this. Verification checks whether the requirements are met (de Graaf, 2014). By verifying the model (automatically) to the requirements, the calculation is based on a product that meets the requirements (Woodcock & Forder, 2012; Honour, 2004). This contributes to a more accurate solution and price. In addition to verification, validation is also an important process within SE. The model can meet the requirements, but not the expectations of the client or the stakeholders. When this happens, customer requirements are not properly converted into measurable requirements (de Graaf, 2014). By means of a visual 3D-model the client can determine whether the product meets his/her expectations (Ghaffarianhoseini, et al., 2016). In order to perform the V&V activity, the following conditions (X) apply:

- 1. SE database with verifiable requirements: to be able to carry out the verification, the requirements must be clear and verifiable (Baker, et al., 2000). Verifiable means that one can check if the requirements are met. For this purpose the requirements must be measurable, and thus clearly describe the performance. These requirements must be stored in a requirement database that is able to communicate with the model and can be used to (automatically) check if the information in de SE database corresponds with the information in the model (Valdes, 2016; Baker, et al., 2000; Polit-Casillas & Howe, 2013). Activity 3.1. Link SE database can be used to develop the requirement database. In order for this communication to take place, the requirements must be linked to functions or geometry (objects) (Valdes, 2016; OMG SysML);
- 2. LOD300/350: to be able to use the model for verification and validation, a model must be developed (Baker, et al., 2000; Valdes, 2016). The elements in this model must be worked out to LOD300 or LOD350 level (BIM Forum, 2016). To be able to verify, the objects must be modelled individually, and one must be able to extract information from this object. This corresponds with LOD300. In order to verify the interfaces between objects, LOD350 is required. In this case, all interfaces between the objects are modelled (BIM Forum, 2016). Activity 1.4. Integral 3D modelling is needed to be able to develop the model;
- 3. **ICT resources**: ICT resources are needed to enable (automatic) verification based on the model (Valdes, 2016; Polit-Casillas & Howe, 2013; OMG SysML);
- 4. **Skills**: skills are required for the verification and validation and for using the ICT resources (Valdes, 2016).

# Activity 1.3. Conflict control

A conflict control can check whether the integral model, developed by different disciplines, is consistent. For example, the architect may add information to the model that conflicts with information added by the manufacturer. A conflict control checks whether there are conflicts between this information. The conflicts are highlighted in the model and can be resolved. This improves the quality of the model (Azhar, Nadeem, Mok, & Leung, 2008), and failure costs can be reduced with 10% of the contract value (Ghaffarianhoseini, et al., 2016). This contributes directly to an accurate tender price. To perform this activity, the following conditions (X) apply:

- 1. **LOD350**: to able to carry out the conflict control, the objects and the interfaces between the objects must be clear. This means that at least LOD350 is required, because the objects and the interfaces between objects are modelled (BIM Forum, 2016). Also, all information from different disciplines must be in one integral model. Activity 1.4. Integral 3D modelling can be used to do this;
- 2. **ICT resources**: ICT resources are needed to carry out the conflict control (Azhar, Nadeem, Mok, & Leung, 2008);
- 3. Skills: skills are needed to carry out the conflict control by means of the ICT resources.

# Activity 1.4. Integral 3D modelling

To be able to calculate, verify and check the model a 3D-model must be developed. And because a 3D-model is more accurate than 2D drawings, the calculation is based on more accurate information (Ghaffarianhoseini, et al., 2016). This contributes to an improved accuracy of the tender price. In addition, modelling helps to gain insight into the complexity of the building and helps to process changes in the design rapidly (Ghaffarianhoseini, et al., 2016). Also, time savings can be achieved up to 7% of the total project time (Ghaffarianhoseini, et al., 2016). But, a time investment is needed in earlier stages of the project, where changes do not cause a lot of costs (Valdes, 2016). To perform this activity, the following conditions (X) apply:

- 1. **Suitable solution/design**: to be able to make a model, the solution must be worked out. In addition, this solution must meet the requirements and other information/specifications (Valdes, 2016; Baker, et al., 2000). Activity 2.1. Trade study can help to choose a solution that fits the requirements;
- 2. LOD300/350: to be able to calculate a tender price a model in which the elements are worked out to (at least) LOD300 is required. Verification and the conflict control requires (at least) LOD350. To achieve this level, time needs to be invested for modelling (Valdes, 2016). However, there is only limited time available in the tender phase and capacity cannot be increased because of the limited tender budgets. Therefore, one has to effectively deal with the limited time. Prioritizing can help with this problem;
- 3. **Prioritization**: to be able to deal with the limited time, one has to determine which parts of the project are most important (Wiegers, 1999). This starts with the requirements analysis. One checks which

requirements are important for a certain phase in the project and should be worked out. This helps to spread activities, such as the requirement specification, design, verification and modelling throughout the process of the project. As a result, activities can also be carried out in parallel. For example: *First, the requirements that are important for the first phase (draft design) are worked out. This package of requirements transfers to the designers. While designing, the requirements for the next phase are specified, and passed on to the designers. The designers transfer their solution for the draft to the modelling team, and work on the solution for the next phase, and so on. Prioritizing is a step performed during the requirements analysis, see Activity 3.1. Link with SE database;* 

- 4. **Working together**: to create an integral model, the different parties must work together in one environment. All information must be stored in one place, creating a single truth for all parties (Valdes, 2016);
- ICT resources: to be able to develop a model, ICT resources are needed (Valdes, 2016; Azhar, Nadeem, Mok, & Leung, 2008);
- 6. Skills: to be able to develop a model and use the ICT resources skills are needed (Valdes, 2016);
- 7. **Organisational conditions**: applying BIM asks for a change in the organisation, to be able to make an integral model with multiple partners and disciplines (Meijer, 2013).

# Activity 1.5. BIM activities for building-flow-simulation (4D-BIM)

4D-BIM includes linking planning information to the model, so that building flows can be mapped (Chau, Anson, & Zhang, 2004). The flow of goods and cranes and the construction of the building site can then be simulated. By implementing the building-flow-simulation, insight can be obtained into the construction site and unforeseen costs can be reduced (Chau, Anson, & Zhang, 2004). This contributes to an improved accuracy. Also, the costs for labour and equipment can be calculated when the 4D information is present in the model (Azhar, Nadeem, Mok, & Leung, 2008). To perform this activity, the following conditions (X) apply:

- 1. **3D-Model with 4D-information**: in addition to standard 3D information, the model must contain planning information (4D information) (Zhang & Hu, 2011). This includes information about time, labour and equipment. By including this information in the model, it is possible to take into account the limitations of labour, equipment, space at the construction site, etc. Also, the information can be used to calculate labour and equipment costs (Zhang & Hu, 2011). However, a time investment is needed for 4D modelling activities. But because there is no extra time available in the tender phase, prioritization is needed, see Activity 1.4. Integral 3D modelling. Important to note is that 3D modelling needs to be conducted before 4D modelling, because the 3D objects are needed to model 4D information;
- 2. Information about the restrictions of the construction site: Information about the site and its constraints must be collected (Zhang & Hu, 2011). Activity 4.2. System and environmental analysis can help to map the constraints of the building site;
- 3. **Requirements regarding 4D-information**: the requirements that affect 4D information must be mapped (Zhang & Hu, 2011). Activity 3.1. Link SE database can help with this;
- 4. **ICT resources**: ICT resources are required to be able to develop the 4D-model and to carry out the simulation (Zhang & Hu, 2011);
- 5. Skills: skills are needed to develop the 4D-model and to carry out the simulation;
- 6. **Organisational conditions**: applying BIM asks for a change in the organisation, to be able to make an integral model with multiple partners and disciplines (Meijer, 2013).

# Activity 1.6. BIM activities for soil analysis

According to the UAC-IC, it is mandatory to align the design or model with the restrictions arising from the soil condition (art. § 13 UAC-IC 2005). This means that the contractor must map the condition of the soil. If the contractor does not do this, he/she is responsible for the additional costs. The liability expires when the contractor can demonstrate that she has done everything possible to map the condition of the soil, and has not been able to see the restrictions (art. § 13 UAC-IC 2005). The BIM activities for soil analysis can help to align the model to the soil restrictions. Specialized companies are developing models where the condition of the soil (including objects, cables and conduits, etc.) has been mapped. (Kessler, et al., 2015). By conflicting this soil model with the developed 3D-model, the restrictions of the soil can be taken into account. This reduces unforeseen costs and therefore contributes directly to the improvement of the accuracy of the tender price. To perform this activity, the following conditions (X) apply:

- 1. **Model of the soil conditions**: to be able to apply this activity, a model of the soil must be available. These are made by different authorities (Kessler, et al., 2015);
- 2. **Integral 3D-model**: to be able to compare the model of the soil an integral 3D-model must be available (Kessler, et al., 2015). Activity 1.4. Integral 3D modelling can be used to develop this integral 3D-model;
- 3. **Conflict control**: using a conflict control, conflicts between the 3D-model of the product and the model of the soil can be identified (Activity 1.3. Conflict control);
- 4. **ICT resources**: suitable ICT resources are required to import a soil model in the 3D-model (Kessler, et al., 2015);
- 5. Skills: skills are needed to be able to use the ICT resources (Kessler, et al., 2015).

# Activity 2.1. Trade study (for design)

To be able to develop an integral 3D-model, the chosen solution must be clear (Baker, et al., 2000). This solution must meet the requirements and (other) information/specifications, such as policies and regulations (Valdes, 2016; Baker, et al., 2000). A trade study can identify suitable solutions that fit the requirements and the scope (Department of Defense, 2001). The different solutions are evaluated using criteria. These criteria may be requirements, but can also be other variables such as feasibility, cost, sustainability or safety. A trade study makes the creation and choice of a solution more transparent. The trade study contributes to the accuracy of the tender price indirectly, by helping the designer to choose the right solution that fits the requirements and the scope. This means that the design need not be modified in a later stage of the project (Office of Engineering and Construction Management, 2003). Modifications can lead to additional costs and therefore an increased bias. Besides this, the trade study helps demonstrate that a solution fits the requirements, which can be beneficial for the quality assurance test of an UAC-IC project. To perform this activity, the following conditions (X) apply:

- 1. Alternatives: different alternatives should be developed that can be compared with each other (Department of Defense, 2001). Optionally, these alternatives can be modelled using Activity 1.4. Integral 3D modelling. The alternatives are derived from the specifications (functions) (Department of Defense, 2001), see Activity 3.1. Link SE database;
- Assessment criteria: assessment criteria must be developed. These are used to evaluate the alternatives. These criteria can be requirements, but also other criteria such as feasibility, cost or time (Department of Defense, 2001; Office of Engineering and Construction Management, 2003);
- 3. Skills: skills are needed to evaluate the alternatives.

# Activity 3.1. Link of the SE database with the model

The data in the SE database describes what the product must do to meet the specifications. It describes how the product yields value for the customer and what is needed to achieve this value (Dori, 2016) The contractor or designer is stimulated to think about requirements, before developing the design (de Graaf, 2014). As a result, a more appropriate solution can be developed, which need not be modified in a later stage of the project. This indirectly contributes to the accuracy of the tender price. In order to be able to use these specifications for verification too, the information must be stored in a central database (Valdes, 2016; Polit-Casillas & Howe, 2013), that is able to communicate with the 3D-model. To do this, the SE database must meet the following conditions (X):

- 1. **Functions**: modelling starts with identifying, naming and describing functions. A function is the main process of a system (Dori, 2016) and describes what the system should do and how well it should perform (Department of Defense, 2001). Functions deliver value, as opposed to objects that only costs money to achieve the value (Dori, 2016). When functions are specified, the solutions and its combination of objects can be developed. These objects will carry out the process of the function;
- 2. Objects: objects are required to carry out the process of a particular function (Dori, 2016) and will be modelled by means of BIM software. The performance of these objects, which is specified in a function, will be verified. The objects must therefore describe this performance and must be linked to the requirements and functions. Besides this, the objects should be described because they form the connection between the 3D-model and the SE database (Polit-Casillas & Howe, 2013);
- 3. **Requirements**: the requirements describe the wishes and expectations of the customer and the stakeholders. These requirements must be defined in clear and measurable performance conditions, so that they can be converted into functions and can be used for verification. This can be done by

means of a requirements analysis. In this process, requirements are *identified*, *prioritized* and *translated* into measureable specifications (Anumba & Evbuomwan, 1997). The identification of requirements is the first step. Requirements are collected from different stakeholders. Secondly, it will be determined which requirements are most important and have the highest priority. Requirements can be prioritized based on different criteria, such as the project phase, risk, stakeholder, costs, etc. Prioritizing helps to make small bundles of requirements instead of implementing them all at once (Wiegers, 1999). Because of this, the implementation of requirements can be spread over time. The contractor only works on the requirements that are important for the corresponding phase. These requirements are then converted into measurable specifications (SMART), and in the end a verification plan. SMART stands for <u>Specific, Measurable, Acceptable, Realistic and Time-bound;</u>

- 4. Information: the database must contain information about the scope, system and stakeholders. This is because requirements, objects and specifications can result from this information (Department of Defense, 2001). Activity 4.2. System and environmental analysis can be used to gather information about the scope, the system and the stakeholders. In addition, other information may be added to the database, such as policies and regulations (Valdes, 2016), see Activity 4.3. Link database policies and regulations;
- 5. **ICT resources**: ICT resources are needed for the database and the connection of the SE database and the 3D-model (Valdes, 2016);
- 6. **Skills**: to be able to carry out the requirement analysis, the functional analysis and be able to work with the ICT resources suitable skills are needed (Woodcock & Forder, 2012).
- 7. **Organisational conditions**: this activity requires a cultural change and a different mind-set (Woodcock & Forder, 2012).

# Activity 4.1. Link model with price database

Working with outdated price information directly results in price deviations and thus reduced accuracy of the tender price. Therefore, one should calculate the prices using actual price information (Liu & Zhu, 2007). A database with the price information can be linked to the model and/or the calculation software. This database can be used for multiple projects and should be kept up-to-date centrally. To perform this activity, the following conditions (X) apply:

- 1. **ICT resources**: ICT resources are needed for the database itself and the connection of the database with the 3D-model;
- 2. Keep database up-to-date: there must be someone who keeps the database up-to-date;
- 3. Availability price information: the price information, from different partners, must be available.

# Activity 4.2. System- and environmental analysis

The goal of the system and environmental analysis is to map the scope, the system and the environment of the system. The entities that are inside and outside the system and the interfaces between the entities are mapped (de Graaf, 2014). This results in insight into the scope, location, construction site, condition of the soil and stakeholders. This information may create new requirements that are of great importance to the project (Department of Defense, 2001). Applying this activity results in an improved accuracy of the tender price, by reducing unforeseen costs caused by the limitations of the scope and its environment. To perform this activity, the following condition (X) applies:

1. Skills: skills are needed to carry out the system- and environmental analysis.

# Activity 4.3. Link model with a database with policies and regulations

In addition to the requirements of the client or stakeholders, specifications may also result from policies and regulations. By including this information in the model and use it to verify the model one can prove if the conditions of the policies and regulations are met. This reduces unforeseen costs and therefore improves the accuracy of the tender price (Valdes, 2016). To perform this activity, the following conditions (X) apply:

- 1. **ICT resources**: ICT resources are needed for the database itself and the connection between the database and the 3D-model (Valdes, 2016);
- 2. Keep database up-to-date: there must be someone who keeps the database up-to-date;

# 3.3. The value and restrictions

Using the combination of SE, BIM and MBSE activities, the accuracy of the tender price can be improved by conducting a more accurate calculation and a reduction of failure costs and unforeseen costs. This is done by using an integral 3D-model for calculation. This model meets the requirements and other information/ specifications, by continuous checks and verification/validation. Besides this, the combination helps to meet the requirements of the UAC-IC contract. Verification by means of the model can be used to demonstrate the fulfilment of the requirements. The verification serves as the quality assurance test, which is compulsory according to the UAC-IC (art §19 UAC-IC 2005). Also, the soil aspects can be mapped by means of analysis and supporting BIM tools. The restrictions or conditions of the soil conditions can be used to develop the design. Taking into account these restrictions is mandatory according to the UAC-IC (art. §13 UAC-IC 2005).

The limitation of the combination of SE, BIM and MBSE is that SE and BIM activities require an investment in time in earlier phases of the project, such as the tender phase (Honour, 2004; Valdes, 2016). This is because in earlier phases of the project it is still possible to influence the costs and changes do not result in a lot of costs, compared to later phases (Valdes, 2016). In later phases this is much more difficult, because more information is fixed. By investing in earlier phases, and properly working out the requirements and solutions and eliminating potential conflicts and mistakes, (failure) costs can be reduced. This contributes to the accuracy of the tender price (Ghaffarianhoseini, et al., 2016; Honour, 2004; Woodcock & Forder, 2012). However, the main difficulty is that there is little time available in the tender phase and tender budgets are tight, which means capacity cannot be increased. It is therefore important to prioritize the requirements, bundle them in small packages and spread the packages over the available time.

# 3.4. Sub-conclusion: Part 1

This chapter describes which combination of SE, BIM and MBSE activities can be applied to improve the accuracy of the tender price of an UAC-IC project according to literature (sub-question 1). The combination works as follows: in order to improve the accuracy of the tender price for an UAC-IC project, literature proposes to calculate the costs based on a model. When using the model for calculation, a price with a bias as low as +/- 3% can be calculated. However, to be able to do this the following conditions apply: (I) an integral model needs to be developed that gives a good reflection of reality, (II) the model must reflect a solution that fits the scope, requirements and expectations of the client, (III) both the model and the solution must meet the contractual requirements and (IV) the restrictions from the scope, applicable policies and regulations and other restrictive information. Therefore, the following activities/processes are required:

# Model:

- 1. The *calculation* is based on an *integral model* with 4D information and current price information, whereby a tender price with a bias of +/- 3% can be calculated;
- 2. The integral model is *verified and validated* according to the requirements using a model-linked SE database, resulting in a model that complies with the customer demands;
- 3. The integral model, which contains information from different disciplines, should not conflict with each other, and therefore requires a *conflict control*. This reduces failure costs up to 10% of the contract value;
- 4. An *integral model* is developed by various disciplines, such as the contractor, architect, installation agencies, etc. As a result, the information on which the tender price is based becomes more accurate and the accuracy of the tender price will be improved. However, integral 3D modelling requires a time investment, while limited time is available. This asks for a more efficient use of the available time (see 8.);
- 5. *4D- information* will be added to the model, such as labour and equipment, so that labour and equipment costs can be calculated and insights can be obtained into the construction site. As a result, unforeseen costs can be reduced and the accuracy of the tender price can be improved;
- 6. The *condition of the soil* is taken into account by clashing the integral 3D-model with a soil model, reducing unforeseen costs due to soil constraints and improving the accuracy of the tender price.

# Solution:

7. A *trade study* is conducted to choose the best alternative that fits the requirements and other information, based on assessment criteria that arise from the requirements and other criteria such as feasibility, cost and time. The accuracy of the information on which the tender price is based, as well as the accuracy of the tender price itself improves.

# Requirements:

8. The model must be linked to a SE database to enable verification to be carried out. The SE database contains information about the requirements, functions and objects. To collect the information for the SE database a requirement analysis is conducted. This analysis consists of three steps: (I) identification of the requirements, (II) analysis and prioritization of the requirements and (III) translation of the requirements into measurable specifications (including functions). The requirement analysis takes time, so prioritization is needed (step II). Prioritizing helps to make small bundles of requirements instead of implementing them all at once. As a result, the implementation of requirements can be spread over time.

# Information:

- 9. The calculation must be based on current price information, by linking the model with a *price database* that is kept up-to-date centrally. Therefore, the accuracy of the tender prices improves;
- 10. The limitations resulting from the scope and the environment of the project should be mapped using a *system and environmental analysis* to highlight the constraints resulting from the scope, location, construction site, condition of the soil and stakeholders. This can reduce unforeseen costs and improve accuracy;
- 11. The model needs to fit the constraints of policies and regulations, by linking the model with a *database with policies and regulations*. This can reduce unforeseen costs caused by restricting policies and regulations and improve the accuracy of the tender price.

These activities help to improve the accuracy of the tender price and also help to meet the requirements of the UAC-IC contract, namely by conducting the quality assurance test and by aligning the project with the soil conditions. However, the activities and especially modelling and the requirement analysis require an investment in time. This is necessary because in earlier phases the costs can still be affected and changes do not result in lots of costs yet. As a result, an accurate product is developed at an early stage. Therefore, time and costs can be saved later on. However, because the time in the tender phase is limited and the tender budgets are tight, the available time must be used efficiently. Therefore, prioritizing the requirements, dividing the requirements in manageable packages and spreading the packages over the available time are important.

# 4. Part 2: Current situation and confrontation

In the previous part, the combination of SE, BIM and MBSE activities that can improve the accuracy of the tender price for an UAC-IC project, according to literature, are described. The next step is to investigate to which extent these activities are applied at DVBH and why there are applied or not (sub-question 2).

**Sub-question 2**: To which extent is the combination of SE, BIM and MBSE activities -that can improve the accuracy of the tender price of an UAC-IC project- applied at DVBH

First, the application of the activities per project will be examined (*within-case analysis*). This analysis results in similarities and differences between the conceptual model (part 1) and the current situation at DVBH (part 2). After this, a cross-case conclusion<sup>1</sup> can be drawn from the application of the activities at DVBH (*cross-case analysis*). The results will be presented in a table, see Table 3 Method Part 2.

TABLE 3 METHOD PART 2

PART 1: CONCEPTUAL MODEL		PART 2: CURRENT SITUATION AND CONFRONTATION		
Activities	Expected pattern	Observed pattern	Similarities and differences	
Activity X.	A results in B via mechanism	Application of activity X at	Similarities and differences between the	
	C with condition(s) X	DVBH.	expected pattern and observed pattern	

# 4.1. Within-case analyse

First, the application of the SE, BIM and MBSE activities per project will be examined and the reason why these activities are applied or not applied will be discussed. The extended results can be found in Appendix 2. Application of SE, BIM and MBSE activities and a summary in Table 4 Within-case analysis. Per container (model, solution, requirements and information) the results will be discussed briefly.

<sup>&</sup>lt;sup>1</sup> The organisational conditions described in the conceptual model have not been examined in detail

# 4.1.1. Model

During the project Theater Wereld van Ontmoeting (WvO), no integral 3D-model has been developed in the tender phase, because there is too little time available. Due to the lack of this model all activities, such as calculation, verification and the conflict control, cannot be applied. Instead of an integral model, drawings and impressions are developed. These are developed in software that is not or very limitedly able to link information to the model, like Sketch-Up. The calculation is conducted by means of (2D) drawings. Verification and validation are carried out by showing the drawings and impressions to the client. Important to note is that the respondents use the same word for verification and validation, and both verification and validation are conducted by showing the drawings to the client. However, some respondents also note that for UAC-IC projects, only showing drawings to the client is not sufficient anymore.

After the tender phase, there is time for modelling and the conflict control. The ICT resources and skills for integral 3D modelling and the conflict control are available. For the building flow simulation these ICT resources and skills are also present, but the activity is not applied (before and after the tender phase) due to a lack of time. However, the respondents state that there is ambition for 4D-BIM because it helps to gain insight into the constraints of the construction site. The ICT resources and skills for the BIM soil analysis and verification based on the model are missing, thus these activities are not applied. In addition, respondents are not very familiar with the BIM tools for soil analysis and state that a soil-drilling test and a thorough analysis of the construction site are already sufficient.

During the C-SMART project also no integral 3D-model has been developed. As a result, the other activities for the container: *model* cannot be applied. Instead of an integral model, drawings and impressions are developed in software such as Sketch-Up or they are developed by hand. The calculation is conducted by means of (2D) drawings. However, after the tender phase, some quantities are exported from the model and have been used to calculate (material) costs. ICT resources are available for exporting quantities. The respondents think that this method is faster and more accurate compared to measuring from 2D drawing, because the 3D-model is more accurate. Verification and validation are carried out by showing the drawings to the client. After the tender phase, the integral 3D-model has been developed and a conflict control has been conducted. The ICT resources and skills for these activities are available. The building flow simulation has not been conducted during and after the tender phase, due to the limited time available. However, ICT resources and skills for this activity are available. The ICT resources and skills for the BIM soil analysis and verification based on the model are missing, and these activities are therefore not applied. The soil analysis is carried out by means of a soil-drilling test and an analysis of the construction site (for example based on existing drawings of the site).

The Unilever project is still in the tender phase. In this phase no integral 3D-model has been developed. The designers use other software, such as Sketch-Up, for impressions and drawings. Based on these impressions and drawings, the costs are calculated. The calculators think that this way of calculating offers advantages, because they can quickly implement optimizations. In a 3D-model, this is more difficult. Due to the lack of an integral 3D model, verification based on the model has not been conducted. There are also no suitable ICT resources available. The verification takes place by showing the drawings to the client. After the tender phase, the verification will be carried out on the basis of verification plans that result from the requirements. These requirements are stored in a SE database (Relatics), but not converted into measurable specifications yet. This is because there is little time available in the tender phase (namely 3 weeks). Therefore, converting requirements into measurable specifications and the development of verification plans are carried out after the tender phase. The building flow simulation has also not been applied, due to the lack of a 3D-model and time. However, the ICT resources and skills for this activity are already available. The ICT resources and skills are lacking for the BIM tools for soil analysis. Also, the respondents do not know this activity. Again, a soil-drilling test and an analysis of the construction site are used to gain insight into the condition of the soil.

During the project Landelijke Opslag Archief (LOA) no integral 3D-model has been developed in the tender phase either. Therefore, the other activities in this container (1. Model) are not performed. The design is developed by means of other software (sometimes 2D software) or by hand. Calculations are developed by using (2D) drawings, even though ICT resources are available to extract quantities from the model and use them for calculation. Verification is conducted by using these (2D) drawings too. The drawings are verified based on verification plans, created in a SE database (Briefbuilder).

Validation is conducted by showing the drawings and impressions to the client. The building flow simulation has not been applied in and after the tender phase due to the lack of a model and time. However, ICT resources and skills for this activity are present. There are no ICT resources and skills available for the BIM tools for soil analysis. The respondents also do not know this activity and use a soil drilling test and a construction site analysis to gain insight into the condition of the soil.

# 4.1.2. Solution

During the WvO project, the trade study has been applied to be able to choose a suitable solution. Different alternatives are developed that are weighed based on requirements and other criteria, such as feasibility, cost and time. The purpose of the trade study is to design a solution that fits the customer's requirements and to develop a competitive tender price. After the tender phase, trade studies are also used to develop optimizations, which can save costs. In UAC-IC projects, the tender price is fixed after awarding the project to the contractor. And when the submitted price is lower due to optimizations, DVBH can create a profit margin.

During the C-SMART project, the trade study has also been applied, again by weighing alternatives based on requirements and other criteria. The trade study has also been applied for the Unilever project. For this project, the strict sustainability requirements and state-of-the-art solution ask for this activity. For LOA, the trade study has also been applied. For this project, alternatives with regard to daylight and energy are important.

# 4.1.3. Requirements

At the WvO project, the BvP procedure, or "*Best Value Procurement*" is applied. The characteristic of this procedure is that the client leaves the completion of the project to the contractor, because he/she is an expert and can therefore develop the best solution for the problem. This approach gives the contractor the freedom to develop creative solutions as long as this solution meets the basic requirements of the client. As a result, few requirements have been described, so DVBH did not consider it necessary to apply a special approach, such as SE. The respondents state they only look which requirements carry the most risk, and then they develop a solution based on this categorisation of requirements. Verification is conducted by showing drawings to the client. In this project, the respondents speak of an "*UAC-IC light*" project because the customer does not value the verification of the requirements very much. Therefore a SE database has not been used for this project. Also, there is a lack of suitable ICT resources for the SE database.

Also during the C-SMART project, no SE database has been used. There was little knowledge of UAC-IC projects and SE that time. The respondents think the application of SE results in too much work. The requirements are prioritized based on importance and an appropriate solution is devised from these requirements. Verification takes place by showing the drawings and impressions to the client.

During the Unilever project a SE pilot has been conducted. The team invested in a SE database (Relatics), in which the requirements are stored and structured. The requirements are linked to functions and objects. However, during the tender phase, the requirements have not yet been converted into measurable specifications or verification plans. This will be done after the tender phase, due to a lack of time during the tender phase. Although a SE database has been developed, it is not linked to an integral 3D-model because there is no model available in the tender phase. There are also no suitable ICT resources available to connect the model with the SE database.

The LOA project involves a public client who uses his/her own method for the specification of their demand. The building must be developed in accordance with the FWR standard, or the norm "*Fysieke Werkomgeving Rijk*". This is a universal office concept developed by the Rijksgebouwdienst, which contains all the requirements the contractor has to meet. This means that a detailed requirement specification has been provided for this project. This specification is provided in a Briefbuilder file. The client also values the verification process, which stimulates DVBH to work with Briefbuilder and an SE approach. The requirements are prioritized by DVBH using risk and phase as criteria. Subsequently, the requirements (for the tender phase) are converted in measurable requirements and verification plans. Furthermore, the requirements are linked to objects and functions. However, the respondents state that this process is very time-consuming. Moreover, Briefbuilder turned out to be not very clear and not easy to use. Attempts were made (after the tender phase) to link the model using a plug-in. But this plug-in did not work properly. So, for this case, a SE database has been used, but the database has not been linked to the model.

# 4.1.4. Information

During the WvO project, a model-linked price database has not been used. There are no suitable ICT resources for this activity. The respondents state that actual price information is being used, but without a model-linked database. The Supply Chain Manager helps keep the prices up-to-date and manages the contracts with partners. Also a model-linked database with policies and regulations has not been used. Again, there are no ICT resources available for this activity. In addition, respondents think that it takes too much time to keep the database up-to-date. Policies and regulations, such as the building decree, are being tested without a model-linked database. However, a system and environmental analysis has been carried out in this project. The construction site, the environment, the stakeholders and the condition of the soil have been mapped. This is done to reduce unforeseen costs.

During the C-SMART project a model-linked price database has not been used either. There are no suitable ICT resources for this activity. The respondents state that they use actual price information from partners, but without a model-linked database. The same applies for the database with policies and regulations. Tests, like the building decree test, are carried out but without the use of a model-linked database. However, a system and environmental analysis has been carried out to map the building site, the environment and the condition of the soil. Again, this is done to reduce unforeseen costs.

During the Unilever project, again no model-linked price database has been used. There are no suitable ICT resources available. Actual price information is used for the calculation, but without a model-linked database. The same applies for the database with policies and regulations. Tests, like the building decree test, are carried out but without the use of a model-linked database. However, a system and environmental analysis has been carried out to map the building site, the environment and the condition of the soil. Again, this is done to reduce unforeseen costs.

For the LOA project the same pattern is visible. No model-linked price database or database with policies and regulations have been used. Actual price information is used for the calculation and tests, like the building decree test, are carried out without using a model-linked database. A system and environmental analysis has been carried out to map the building site, the environment and the condition of the soil. This is done to reduce unforeseen costs.

#### TABLE 4 WITHIN-CASE ANALYSIS

Activity	Application**			
	WvO	C-SMART	Unilever	LOA
		`1. MODEL		
<u>1.1. Calculation based</u> on the model	Not applied: Calculation is done by hand, based on (2D) drawings. The 3D-model was not developed and therefore not verified. No ICT resources or skills are available	Not applied: Calculation is done by hand, based on (2D) drawings. The 3D-model was not developed and therefore not verified. ICT resources are available for exporting quantities	Not applied: Calculation is done by hand, based on (2D) drawings. The 3D-model was not developed and therefore not verified. No ICT resources or skills available. Respondents think 2D drawings are easier than a 3D-model, to be able to perform cost-optimizations.	Not applied: Calculation is done by hand, based on (2D) drawings. The 3D-model was not developed and therefore not verified. ICT resources are available for exporting quantities
1.2. V&V of the model	Partially applied: Verification and validation are carried out by showing drawings and impressions to the client. There are no SE database, model, ICT resources and skills available.	Partially applied: Verification and validation are carried out by showing drawings and impressions to the client. There are no SE database, model, ICT resources and skills available.	Partially applied: No verification plans are made during the tender phase and verification is carried out by showing the drawings to the client. After the tender phase verification plans are made and verification is conducted by means of these plans. The SE database is available, but requirements are not measurable in the tender phase. There is also no model available.	Partially applied: No verification based on the model, because of the lack of a model. Verification carried out by means of verification plans developed in the tender phase but without the use of the model. Validation carried out by showing drawings to the client.
1.3. Conflict control	Not applied: Not applied in the tender phase, because of a lack of a model and time. But, the activity is applied after the tender phase. ICT resources and skills available.	Not applied: Not applied in the tender phase, because of a lack of a model and time. But, the activity is applied after the tender phase. ICT resources and skills available.	Not applied: Not applied in the tender phase, because of a lack of a model and time. But, the activity is applied after the tender phase. ICT resources and skills available.	Not applied: Not applied in the tender phase, because of a lack of a model and time. But, the activity is applied after the tender phase. ICT resources and skills available.
<u>1.4. Integral 3D</u> modelling	Not applied: Not applied in the tender phase, because of a lack of time. But, the activity is applied after the tender phase. ICT resources and skills available.	Not applied: Not applied in the tender phase, because of a lack of time. But, the activity is applied after the tender phase. ICT resources and skills available.	Not applied: Not applied in the tender phase, because of a lack of time. ICT resources and skills available.	Not applied: Not applied in the tender phase, because of a lack of time. But, the activity is applied after the tender phase. ICT resources and skills available.

1.5. Building Flow Simulation (4D-BIM)	Not applied: Not applied in and after the tender phase, due to a lack of time and a model. Ambition, ICT resources and skills available. Information about restrictions of the construction site available.	Not applied: Not applied in and after the tender phase, due to a lack of time and a model. ICT resources and skills available. Information about restrictions of the construction site available.	Not applied: Not applied in the tender phase, due to a lack of time and a model. ICT resources and skills available. Information about restrictions of the construction site available.	Not applied: Not applied in and after the tender phase, due to a lack of time and a model. ICT resources and skills available. Information about restrictions of the construction site available.
<u>1.6. BIM tools for soil</u> analysis	Not applied: Not applied, because of the absence of ICT resources, skills and a model. Respondents think a soil drilling test and a construction site analysis are sufficient.	Not applied: Not applied, because of the absence of ICT resources, skills and a model. Respondents think a soil drilling test and a construction site analysis are sufficient.	Not applied: Not applied, because of the absence of ICT resources, skills and a model. Respondents think a soil drilling test and a construction site analysis are sufficient.	Not applied: Not applied, because of the absence of ICT resources, skills and a model. Respondents think a soil drilling test and a construction site analysis are sufficient.
		2. SOLUTION	1	
2.1. Trade study	Applied: Alternatives are developed and weighed based on requirements and other criteria.	Applied: Alternatives are developed and weighed based on requirements and other criteria.	Applied: Alternatives are developed and weighed based on requirements and other criteria.	Applied: Alternatives are developed and weighed based on requirements and other criteria.
		3. REQUIREMENTS		
3.1. Link of the SE database with the model	Not applied: Requirements are only prioritized based on risk and a suitable solution is developed based on these requirements. No SE database and skills are available. Information about the scope, system and stakeholders has been collected.	Not applied: Requirements are only prioritized based on importance and a suitable solution is developed based on these requirements. No SE database and skills are available. Information about the scope, system and stakeholders has been collected.	Partially applied: Requirements are stored in a SE database (Relatics) but are not converted into measurable requirements. This is done after the tender phase. Requirements are linked to objects and functions. However, the SE database is not linked with the model because of the absence of ICT resources.	Partially applied: Requirements are stored in a SE database (Briefbuilder) and are converted into measurable requirements and verification plans. Requirements are linked to objects and functions. However, the SE database is not linked with the model because of the absence of ICT resources.
		3. INFORMATION		
4.1. Link model with price database	Not applied: Not applied because of the absence of ICT resources. But, actual price information is used without a model- linked database	Not applied: Not applied because of the absence of ICT resources. But, actual price information is used without a model-	Not applied: Not applied because of the absence of ICT resources. But, actual price information is used without a model-	Not applied: Not applied because of the absence of ICT resources. But, actual price information is used without a model-

4.2. System- and environmental analysis	Applied: Construction site, environment, stakeholders and condition of the soil are examined.	Applied: Construction site, environment, stakeholders and condition of the soil are examined.	Applied: Construction site, environment, stakeholders and condition of the soil are examined.	Applied: Construction site, environment, stakeholders and condition of the soil are examined.
4.3. Link model with	Not applied:	Not applied:	Not applied:	Not applied:
database with policies	Not applied because of the absence of			
and regulations	ICT resources and a lack of time to	ICT resources and a lack of time to	ICT resources and a lack of time to	ICT resources and a lack of time to
	keep the database up-to-date. But,			
	policies and regulations are examined			
	separately without a model-linked			
	database (e.g. Building decree test)			

\*\* red cell= not applied | orange cell= partially applied | green cell=applied

# 4.2. Cross-case analysis

In this section, a cross-case conclusion will be drawn from the application of the SE, BIM and MBSE activities at DVBH. Per container (model, solution, requirements and information) the conclusions will be discussed. A summary can be found in Table 5 Cross-case analysis.

# 4.2.1. Model

In all projects, no integral 3D BIM model has been developed during the tender phase of the project. The reason is a lack of time. The design is developed by hand or by means of other software such as Sketch-up or 2D. As a result, all other activities for container 1. Model are not applied. In all projects, the calculation is conducted based on (2D) drawings and impressions instead of the model. In the Unilever project, respondents note that they can process optimizations more easily with 2D drawings compared to a complex 3D-model. In 2/4 projects (C-SMART and LOA), respondents indicate that there are already ICT resources available to extract quantities from the model for the calculation. However, due to the absence of an integral model in the tender phase, these resources are not used. After the tender phase, an integral 3D-model has been developed in all projects. Also the conflict control is carried out after the tender phase. The ICT resources and skills for these activities are available.

In 2/4 projects (WvO and C-SMART), verification is carried out by showing the drawings and impressions to the client. Due to the absence of an integral model, the model is not used for verification. During WvO, the respondents indicate that the client does not value verification and quality assurance very much. In this case, the respondents speak of an "UAC-IC light" project. Also, some respondents confuse verification and validation. They think these activities are the same thing, namely showing drawings to the client. However, some respondents also note that this "old way" of verification/validation is not sufficient anymore. During the LOA project there was an incentive from the client to verify the requirements. This is mainly due to the type of client (Rijksgebouwendienst). At Unilever there also was an incentive to carry out the verification, but this incentive came from DVBH herself. Here, a SE pilot was carried out by means of a SE database, which contains requirements, objects, functions and potential risks, activities and work packages. Verification, by means of verification plans that were developed in the SE database, is also part of this pilot. However, in the tender phase, the requirements have only been put into the database, but have not yet been converted into measurable specifications and verification plans. Both projects (LOA and Unilever) do not use a model for verification. There are no suitable ICT resources available for this activity. In all projects validation is conducted by showing the drawings and impressions to the client. After the tender phase, the model is used for validation.

In none of the four projects a building flow simulation has been carried out. This is because no integral BIM model is available in the tender phase. There is too little time available to develop this model, including 4D information. However, in the WvO project, respondents indicate that there is ambition for this activity, but simply not the time. However, in all projects, the respondents indicate that there are already ICT resources and skills available at DVBH to perform the building flow simulation. The BIM tools for soil analysis have not been applied in any of the four projects. Most respondents do not know this activity and no ICT resources are available. All projects use a soil drilling test and construction site analysis for soil analysis instead of the BIM tools. Respondents think that these activities are sufficient.

Thus, from the analysis it can be concluded that none of the activities for the container "**1. Model**" are applied. So there is a big gap between "what is theoretically possible" and "what DVBH does". The reason is that there is no integral 3D-model available for carrying out the activities. This is due to a lack of time, while the respondents indicate that there is ambition for 3D-modelling in the tender phase in order to gain insight into the complexity of the building and the interfaces.

# 4.2.2. Solution

All four projects use the trade study. Different alternatives are developed and the best solution is chosen by using the requirements and other variables, such as feasibility, durability and time, as criteria. During the tender phase, the goal of the trade study is to find a suitable solution and to calculate a competitive price. After the tender phase, the trade study helps to apply optimizations to save costs and create a profit margin. This is daily practice for DVBH. So, there is a match between the theoretical possibilities and the current situation at DVBH.

# 4.2.3. Requirements

In 2/4 projects (WvO and C-SMART) no requirement database has been used. In these projects, the prioritization of requirements is based on risk or importance. After this prioritization a solution is developed that fits these requirements. The requirements are not translated into measurable specifications. At WvO, this is because there were very few requirements specified due to the BvP procedure. At C-SMART this is because SE was not yet known at DVBH and respondents state it takes too much time to set up the database. In the other project (Unilever and LOA), a database has been used, but has not been linked to the model due to the lack of appropriate ICT resources and a 3D-model. At LOA, the requirements in the database were prioritized based on risk and phase and are translated into measurable specifications during the tender phase. Verification plans are also developed from these requirements. At Unilever, the requirements are only stored in the database and prioritized based on risk. The translation and development of verification plans are carried out after the tender phase. However, in both projects (Unilever and LOA) functions and objects have been specified and linked to the requirements during the tender phase.

Thus, from the analysis can be concluded that DVBH partially applies the activity, but not yet completely. DVBH can therefore further improve this activity. The reason for not using the activity to its full potential is that DVBH is not very familiar with SE. They recently started with pilots, such as Unilever, mainly because of projects such as LOA. There is also a need for an integral 3D-model and suitable ICT resources to link the SE database with the model.

# 4.2.4. Information

In all four projects, a system and environmental analysis was conducted to map the site, environment, condition of the soil and stakeholders. This is done to reduce unforeseen costs. None of the projects used a price-linked database, due to the lack of appropriate ICT resources. The respondents indicate that actual price information is being used for the calculation, but not by means of a model-linked database. For the same reason the model-linked database with policies and regulations has not been used. The respondents state they do take into account policies and regulations, for example by means of a building decree test. However, they do not use a model-linked database. Again, no ICT resources are available for this activity.

Thus, from this analysis can be concluded that only a system and environmental analysis was applied. The model-linked database was not applied. However, the information contained in this database, such as price information and policies and regulations, have been collected but not actively linked to the model. The respondents indicate that it takes a lot of time to keep such databases up-to-date. So, there is a gap between theory and practice, but this is largely due to the lack of ICT resources and automation.

Activities	Application**			
	1. MODEL			
1.1. Calculation based	In all projects no calculation based on to the model has been applied, due to the lack of a model			
on the model	in which the elements are worked out to LOD 300/400 level. Calculations are based on drawings			
	and impressions. In 2/4 projects, ICT resources are available for exporting quantities, but not			
	yet for calculation based on the model			
	Conditions: (I) No LOD300/350 level, (II) no 4D info linked to the model, (III) no verification of			
	the model, (IV) no integral 3D modelling in the tender phase, but after the tender phase, (V) no			
	link with a price database, (VI) ICT resources for exporting quantities available, but not for			
	automatic calculation, (VII) skills not always available, calculation carried out by hand.			
	Pre-activities: 1.2/1.3/1.4/1.5/4.1			
1.2. V&V of the model	For 2/4 projects (WvO and C-SMART) verification has been carried out by showing drawings or			
	impressions to the client. In the other two projects (Unilever and LOA) verification plans are			
	used, but only for LOA it is used during the tender phase. Due to the lack of the model, the			
	model has not been used for verification and validation in all projects. After the tender phase,			
	there is a model, and it is used for validation but not for verification			
	Conditions: (I) SE database (Relatics) available, (II) No LOD300/350 level, (III) no suitable ICT			
	resources for linking database with model, (IV) no skills available for verification based on the			
	model, but skills available for validation based on the model (after the tender phase)			
	Pre-activities: 1.4/3.1			

#### TABLE 5 CROSS-CASE ANALYSIS

1.3. Conflict control	In all projects, no conflict control has been carried out in the tender phase, because there is no
	3D-model available. After the tender phase, the model is available and this activity is
	conducted. ICT resources and skills are available.
	Conditions: (I) no LOD350 in tender phase, only after the tender phase, (II) ICT resources
	available, (III) skills available
	Pre-activities: 1.4
1.4. Integral 3D	In all projects there is no integral model in the tender phase, due to the lack of time. After the
modelling	tender phase this activity is carried out, because there is more time available. The suitable
<u></u>	solution ICT resources and skills are available (both in and after the tender phase)
	Conditions: (I) suitable solution available (II) no LOD300/350 in tender phase, only after the
	tender phase (III) prioritization based on risks importance and (1/4 projects) phase (IV)
	integral cooperation in one model only after tender phase. (V) ICT resources available. (VI) skills
	available
	Pro activities: 0.1/2.1/4.2
	Pre-activities: 2.1/3.1/4.3
1.5. Building Flow	In all projects, no building flow simulation has been carried out during the tender phase,
Simulation (4D-BIM)	because of the absence of a model and a lack of time. After the tender phase this activity has
	also not been carried out, due to a lack of time. ICT resources and skills are available.
	Conditions: (I) no model with 4D info, (II) information about restriction construction site
	available, (III) requirements about construction site/planning available (IV) ICT resources
	available, (V) skills available
	Pre-activities: 1.4/3.1/4.2
1.6. BIM tools for soil	In all projects, this activity has not been applied due to a lack of a soil model, a 3D model and
<u>analysis</u>	appropriate ICT resources and skills
	Conditions: (I) no soil model available, (II) no 3D model available, (III) no conflict control
	conducted, (IV) no ICT resources available, (V) no skills available
	Pre-activities: 1.3/1.4
	2. SOLUTION
2.1. Trade study	In all projects, this activity has been applied. Alternatives are developed and weighed using
	requirements and other criteria
	Conditions: (I) alternatives are developed, (II) requirements and other variables used as
	assessment criteria, (III) skills available
	assessment criteria, (III) skills available 3. REQUIREMENTS
3.1. Link of the SE	assessment criteria, (III) skills available  3. REQUIREMENTS In 2/4 projects (WVo and C-SMART), no SE database has been developed, and requirements are
3.1. Link of the SE database with the	assessment criteria, (III) skills available  3. REQUIREMENTS In 2/4 projects (WVo and C-SMART), no SE database has been developed, and requirements are prioritized based on risk and importance, after which a solution is developed based on the most
3.1. Link of the SE database with the model	assessment criteria, (III) skills available 3. REQUIREMENTS In 2/4 projects (WVo and C-SMART), no SE database has been developed, and requirements are prioritized based on risk and importance, after which a solution is developed based on the most important or risky requirements. In the other two projects (Unilever and LOA) there is an SE
3.1. Link of the SE database with the model	assessment criteria, (III) skills available <b>3. REQUIREMENTS</b> In 2/4 projects (WVo and C-SMART), no SE database has been developed, and requirements are prioritized based on risk and importance, after which a solution is developed based on the most important or risky requirements. In the other two projects (Unilever and LOA) there is an SE database, but this database has not been linked to the model due to the absence of appropriate
3.1. Link of the SE database with the model	assessment criteria, (III) skills available <b>3. REQUIREMENTS</b> In 2/4 projects (WVo and C-SMART), no SE database has been developed, and requirements are prioritized based on risk and importance, after which a solution is developed based on the most important or risky requirements. In the other two projects (Unilever and LOA) there is an SE database, but this database has not been linked to the model due to the absence of appropriate ICT resources. In only 1/4 projects (LOA), the requirements have been converted into
3.1. Link of the SE database with the model	assessment criteria, (III) skills available <b>3. REQUIREMENTS</b> In 2/4 projects (WVo and C-SMART), no SE database has been developed, and requirements are prioritized based on risk and importance, after which a solution is developed based on the most important or risky requirements. In the other two projects (Unilever and LOA) there is an SE database, but this database has not been linked to the model due to the absence of appropriate ICT resources. In only 1/4 projects (LOA), the requirements have been converted into measurable specifications and verification plans during the tender phase.
3.1. Link of the SE database with the model	assessment criteria, (III) skills available <b>3. REQUIREMENTS</b> In 2/4 projects (WVo and C-SMART), no SE database has been developed, and requirements are prioritized based on risk and importance, after which a solution is developed based on the most important or risky requirements. In the other two projects (Unilever and LOA) there is an SE database, but this database has not been linked to the model due to the absence of appropriate ICT resources. In only 1/4 projects (LOA), the requirements have been converted into measurable specifications and verification plans during the tender phase. <b>Conditions:</b> (I) in 2/4 projects functions specified, (III) in 2/4 projects objects specified, (III) in 2/4
3.1. Link of the SE database with the model	assessment criteria, (III) skills available <b>3. REQUIREMENTS</b> In 2/4 projects (WVo and C-SMART), no SE database has been developed, and requirements are prioritized based on risk and importance, after which a solution is developed based on the most important or risky requirements. In the other two projects (Unilever and LOA) there is an SE database, but this database has not been linked to the model due to the absence of appropriate ICT resources. In only 1/4 projects (LOA), the requirements have been converted into measurable specifications and verification plans during the tender phase. <b>Conditions:</b> (I) in 2/4 projects functions specified, (II) in 2/4 projects objects specified, (III) in 2/4 projects requirements stored in database. In 1/4 projects requirements converted into
3.1. Link of the SE database with the model	assessment criteria, (III) skills available <b>3. REQUIREMENTS</b> In 2/4 projects (WVo and C-SMART), no SE database has been developed, and requirements are prioritized based on risk and importance, after which a solution is developed based on the most important or risky requirements. In the other two projects (Unilever and LOA) there is an SE database, but this database has not been linked to the model due to the absence of appropriate ICT resources. In only 1/4 projects (LOA), the requirements have been converted into measurable specifications and verification plans during the tender phase. <b>Conditions:</b> (I) in 2/4 projects functions specified, (II) in 2/4 projects objects specified, (III) in 2/4 projects requirements atored in database. In 1/4 projects requirements converted into measurable requirements and verification plans. Prioritization based on risk and phase, (IV) for
3.1. Link of the SE database with the model	assessment criteria, (III) skills available <b>3. REQUIREMENTS</b> In 2/4 projects (WVo and C-SMART), no SE database has been developed, and requirements are prioritized based on risk and importance, after which a solution is developed based on the most important or risky requirements. In the other two projects (Unilever and LOA) there is an SE database, but this database has not been linked to the model due to the absence of appropriate ICT resources. In only 1/4 projects (LOA), the requirements have been converted into measurable specifications and verification plans during the tender phase. <b>Conditions</b> : (I) in 2/4 projects functions specified, (II) in 2/4 projects objects specified, (III) in 2/4 projects requirements and verification plans. Prioritization based on risk and phase, (IV) for all projects no information in the database, but information about system and environment has
3.1. Link of the SE database with the model	assessment criteria, (III) skills available <b>3. REQUIREMENTS</b> In 2/4 projects (WVo and C-SMART), no SE database has been developed, and requirements are prioritized based on risk and importance, after which a solution is developed based on the most important or risky requirements. In the other two projects (Unilever and LOA) there is an SE database, but this database has not been linked to the model due to the absence of appropriate ICT resources. In only 1/4 projects (LOA), the requirements have been converted into measurable specifications and verification plans during the tender phase. <b>Conditions</b> : (I) in 2/4 projects functions specified, (II) in 2/4 projects objects specified, (III) in 2/4 projects requirements and verification plans. Prioritization based on risk and phase, (IV) for all projects no information in the database, but information about system and environment has been collected (V) ICT resources for the database available, but the database is not linked with
3.1. Link of the SE database with the model	assessment criteria, (III) skills available <b>3. REQUIREMENTS</b> In 2/4 projects (WVo and C-SMART), no SE database has been developed, and requirements are prioritized based on risk and importance, after which a solution is developed based on the most important or risky requirements. In the other two projects (Unilever and LOA) there is an SE database, but this database has not been linked to the model due to the absence of appropriate ICT resources. In only 1/4 projects (LOA), the requirements have been converted into measurable specifications and verification plans during the tender phase. <b>Conditions:</b> (I) in 2/4 projects functions specified, (II) in 2/4 projects objects specified, (III) in 2/4 projects requirements stored in database. In 1/4 projects requirements converted into measurable requirements and verification plans. Prioritization based on risk and phase, (IV) for all projects no information in the database, but information about system and environment has been collected (V) ICT resources for the database available, but the database is not linked with the model, (VII) skills not or limitedly available
3.1. Link of the SE database with the model	assessment criteria, (III) skills available <b>3. REQUIREMENTS</b> In 2/4 projects (WVo and C-SMART), no SE database has been developed, and requirements are prioritized based on risk and importance, after which a solution is developed based on the most important or risky requirements. In the other two projects (Unilever and LOA) there is an SE database, but this database has not been linked to the model due to the absence of appropriate ICT resources. In only 1/4 projects (LOA), the requirements have been converted into measurable specifications and verification plans during the tender phase. <b>Conditions:</b> (I) in 2/4 projects functions specified, (II) in 2/4 projects objects specified, (III) in 2/4 projects requirements stored in database. In 1/4 projects requirements converted into measurable requirements and verification plans. Prioritization based on risk and phase, (IV) for all projects no information in the database, but information about system and environment has been collected (V) ICT resources for the database available, but the database is not linked with the model, (VII) skills not or limitedly available <b>Pre-activities:</b> 4.2.
3.1. Link of the SE database with the model	assessment criteria, (III) skills available <b>3. REQUIREMENTS</b> In 2/4 projects (WVo and C-SMART), no SE database has been developed, and requirements are prioritized based on risk and importance, after which a solution is developed based on the most important or risky requirements. In the other two projects (Unilever and LOA) there is an SE database, but this database has not been linked to the model due to the absence of appropriate ICT resources. In only 1/4 projects (LOA), the requirements have been converted into measurable specifications and verification plans during the tender phase. <b>Conditions:</b> (I) in 2/4 projects functions specified, (II) in 2/4 projects objects specified, (III) in 2/4 projects requirements stored in database. In 1/4 projects requirements converted into measurable requirements and verification plans. Prioritization based on risk and phase, (IV) for all projects no information in the database, but information about system and environment has been collected (V) ICT resources for the database available, but the database is not linked with the model, (VII) skills not or limitedly available <b>Pre-activities:</b> 4.2. <b>4. INFORMATION</b>
3.1. Link of the SE database with the model 4.1. Link model with	assessment criteria, (III) skills available <b>3. REQUIREMENTS</b> In 2/4 projects (WVo and C-SMART), no SE database has been developed, and requirements are prioritized based on risk and importance, after which a solution is developed based on the most important or risky requirements. In the other two projects (Unilever and LOA) there is an SE database, but this database has not been linked to the model due to the absence of appropriate ICT resources. In only 1/4 projects (LOA), the requirements have been converted into measurable specifications and verification plans during the tender phase.Conditions: (I) in 2/4 projects functions specified, (II) in 2/4 projects objects specified, (III) in 2/4 projects requirements and verification plans. Prioritization based on risk and phase, (IV) for all projects no information in the database, but information about system and environment has been collected (V) ICT resources for the database available, but the database is not linked with the model, (VII) skills not or limitedly availablePre-activities: 4.2. <b>LIFORMATION</b> In all projects, this activity has not been applied due to the lack of ICT resources. But, actual
3.1. Link of the SE database with the model 4.1. Link model with price database	assessment criteria, (III) skills available <b>3. REQUIREMENTS</b> In 2/4 projects (WVo and C-SMART), no SE database has been developed, and requirements are prioritized based on risk and importance, after which a solution is developed based on the most important or risky requirements. In the other two projects (Unilever and LOA) there is an SE database, but this database has not been linked to the model due to the absence of appropriate ICT resources. In only 1/4 projects (LOA), the requirements have been converted into measurable specifications and verification plans during the tender phase. <b>Conditions:</b> (I) in 2/4 projects functions specified, (III) in 2/4 projects objects specified, (III) in 2/4 projects requirements stored in database. In 1/4 projects requirements converted into measurable requirements and verification plans. Prioritization based on risk and phase, (IV) for all projects no information in the database, but information about system and environment has been collected (V) ICT resources for the database available, but the database is not linked with the model, (VII) skills not or limitedly available <b>Pre-activities</b> : 4.2. <b>1. NFORMATION</b> In all projects, this activity has not been applied due to the lack of ICT resources. But, actual price information is used without a model-linked database.
3.1. Link of the SE database with the model 4.1. Link model with price database	assessment criteria, (III) skills available <b>3. REQUIREMENTS</b> In 2/4 projects (WVo and C-SMART), no SE database has been developed, and requirements are prioritized based on risk and importance, after which a solution is developed based on the most important or risky requirements. In the other two projects (Unilever and LOA) there is an SE database, but this database has not been linked to the model due to the absence of appropriate ICT resources. In only 1/4 projects (LOA), the requirements have been converted into measurable specifications and verification plans during the tender phase. <b>Conditions:</b> (I) in 2/4 projects functions specified, (II) in 2/4 projects objects specified, (III) in 2/4 projects requirements stored in database. In 1/4 projects requirements converted into measurable requirements and verification plans. Prioritization based on risk and phase, (IV) for all projects no information in the database, but information about system and environment has been collected (V) ICT resources for the database available, but the database is not linked with the model, (VII) skills not or limitedly available <b>Pre-activities:</b> 4.2. <b>1. INFORMATION</b> In all projects, this activity has not been applied due to the lack of ICT resources. But, actual price information is used without a model-linked database. <b>Conditions:</b> (I) no ICT resources available, (II) no database available, so no one keeps it up-to-
3.1. Link of the SE database with the model 4.1. Link model with price database	assessment criteria, (III) skills available <b>3. REQUIREMENTS</b> In 2/4 projects (WVo and C-SMART), no SE database has been developed, and requirements are prioritized based on risk and importance, after which a solution is developed based on the most important or risky requirements. In the other two projects (Unilever and LOA) there is an SE database, but this database has not been linked to the model due to the absence of appropriate ICT resources. In only 1/4 projects (LOA), the requirements have been converted into measurable specifications and verification plans during the tender phase. <b>Conditions:</b> (I) in 2/4 projects functions specified, (II) in 2/4 projects objects specified, (III) in 2/4 projects requirements stored in database. In 1/4 projects requirements converted into measurable requirements and verification plans. Prioritization based on risk and phase, (IV) for all projects no information in the database, but information about system and environment has been collected (V) ICT resources for the database available, but the database is not linked with the model, (VII) skills not or limitedly available <b>Pre-activities</b> : 4.2. <b>1. INFORMATION</b> In all projects, this activity has not been applied due to the lack of ICT resources. But, actual price information is used without a model-linked database. <b>Conditions</b> : (I) no ICT resources available, (II) no database available, so no one keeps it up-to- <b>date</b> , (III) price information is available, but not stored in a database
3.1. Link of the SE database with the model 4.1. Link model with price database 4.2. System- and	assessment criteria, (III) skills available <b>3. REQUIREMENTS</b> In 2/4 projects (WVo and C-SMART), no SE database has been developed, and requirements are prioritized based on risk and importance, after which a solution is developed based on the most important or risky requirements. In the other two projects (Unilever and LOA) there is an SE database, but this database has not been linked to the model due to the absence of appropriate ICT resources. In only 1/4 projects (LOA), the requirements have been converted into measurable specifications and verification plans during the tender phase. <b>Conditions</b> : (I) in 2/4 projects functions specified, (II) in 2/4 projects objects specified, (III) in 2/4 projects requirements stored in database. In 1/4 projects requirements converted into measurable requirements and verification plans. Prioritization based on risk and phase, (IV) for all projects no information in the database, but information about system and environment has been collected (V) ICT resources for the database available, but the database is not linked with the model, (VII) skills not or limitedly available <b>Pre-activities</b> : 4.2. <b>4. INFORMATION</b> In all projects, this activity has not been applied due to the lack of ICT resources. But, actual price information is used without a model-linked database. <b>Conditions</b> : (I) no ICT resources available, (II) no database available, so no one keeps it up-to- date, (III) price information is available, but not stored in a database In all projects, this activity has been applied. The construction site, the environment, the
3.1. Link of the SE database with the model 4.1. Link model with price database 4.2. System- and environmental analysis	assessment criteria, (III) skills available <b>3. REQUIREMENTS</b> In 2/4 projects (WVo and C-SMART), no SE database has been developed, and requirements are prioritized based on risk and importance, after which a solution is developed based on the most important or risky requirements. In the other two projects (Unilever and LOA) there is an SE database, but this database has not been linked to the model due to the absence of appropriate ICT resources. In only 1/4 projects (LOA), the requirements have been converted into measurable specifications and verification plans during the tender phase. <b>Conditions</b> : (I) in 2/4 projects functions specified, (II) in 2/4 projects objects specified, (III) in 2/4 projects requirements stored in database. In 1/4 projects requirements converted into measurable requirements and verification plans. Prioritization based on risk and phase, (IV) for all projects no information in the database, but information about system and environment has been collected (V) ICT resources for the database available, but the database is not linked with the model, (VII) skills not or limitedly available <b>Pre-activities</b> : 4.2. <b>4. INFORMATION</b> In all projects, this activity has not been applied due to the lack of ICT resources. But, actual price information is used without a model-linked database. <b>Conditions</b> : (I) no ICT resources available, (II) no database available, so no one keeps it up-to- date, (III) price information is available, but not stored in a database In all projects, this activity has been applied. The construction site, the environment, the stakeholders and the soil condition have been analysed.
3.1. Link of the SE         database with the         model         4.1. Link model with         price database         4.2. System- and         environmental analysis	assessment criteria, (III) skills available 3. REQUIREMENTS In 2/4 projects (WVo and C-SMART), no SE database has been developed, and requirements are prioritized based on risk and importance, after which a solution is developed based on the most important or risky requirements. In the other two projects (Unilever and LOA) there is an SE database, but this database has not been linked to the model due to the absence of appropriate ICT resources. In only 1/4 projects (LOA), the requirements have been converted into measurable specifications and verification plans during the tender phase. Conditions: (I) in 2/4 projects functions specified, (III) in 2/4 projects objects specified, (III) in 2/4 projects requirements stored in database. In 1/4 projects requirements converted into measurable requirements and verification plans. Prioritization based on risk and phase, (IV) for all projects no information in the database, but information about system and environment has been collected (V) ICT resources for the database available, but the database is not linked with the model, (VII) skills not or limitedly available Pre-activities: 4.2. Conditions: (I) no ICT resources available, (II) no database available, so no one keeps it up-to- date, (III) price information is available, but not stored in a database In all projects, this activity has been applied. The construction site, the environment, the stakeholders and the soil condition have been analysed. Conditions: (I) skills available
3.1. Link of the SE         database with the         model         4.1. Link model with         price database         4.2. System- and         environmental analysis         4.3. Linked model with	assessment criteria, (III) skills available
3.1. Link of the SE         database with the         model         4.1. Link model with         price database         4.2. System- and         environmental analysis         4.3. Linked model with         database with policies	assessment criteria, (III) skills available
3.1. Link of the SE         database with the         model         4.1. Link model with         price database         4.2. System- and         environmental analysis         4.3. Linked model with         database with policies         and regulations	assessment criteria, (III) skills available

# 4.3. Sub conclusion: Part 2

This chapter described to which extent the SE, BIM and MBSE activities, which can improve the accuracy of the tender price for an UAC-IC project according to literature, are applied at DVBH (part-question 2). Per container in Figure 2 Scheme conceptual model (model, solution, requirements and information), the following points about the application of the activities in the tender phase of an UAC-IC project can be concluded:

# Model:

- 1. The model is <u>not</u> used for calculation, due to the lack of an integral 3D-model in the tender phase. However, there are already ICT resources for the calculation of quantities available. The calculation is still performed manually by means of drawings and by measuring from these drawings.
- The model is <u>not</u> verified, due to the lack of a model, suitable ICT resources and skills. The verification is conducted (in 3/4 projects) by showing drawings to the client and (in 1/4 projects) by verifying the drawings using verification plans;
- 3. No conflict control <u>is</u> conducted, due to the lack of a model in the tender phase. After the tender phase a model is available, and the conflict control is performed. ICT resources and skills are available;
- Integral 3D modelling is <u>not</u> performed during the tender phase, but only after the tender phase. In the tender phase, there is too little time available for modelling. ICT resources and skills are available. In the tender phase, the design is developed by hand or using other resources, for example Sketch-Up;
- 5. The building flow simulation is <u>not</u> conducted, due to the lack of a model and time in the tender phase. After the tender phase, there is also a lack of time. However, ICT resources and skills are available;
- 6. The BIM tools for soil analysis are <u>not</u> carried out, due to the lack of a model of the soil, a 3D-model and appropriate ICT resources and skills. In addition, respondents think that a soil-drilling test and a construction site analysis are sufficient.

# Solution:

7. The trade study <u>is</u> used to be able to choose the most suitable alternative based on requirements and other assessment criteria. This helps to calculate a competitive price in the tender phase and save costs and generate a profit margin after the tender phase.

# **Requirements**:

8. There <u>are</u> ICT resources for the SE database available, but <u>no</u> resources for linking the database with the integral 3D-model. In 3/4 projects the requirements are only prioritized based on risk and in only one project based on the phase. In only one project the requirements are translated into measurable specifications. In the other projects, requirements are sorted based on risk or importance, and a suitable solution for the most important requirements is developed. No packages are developed that are spread over time and the activities do not run parallel.

# Information:

- 9. The model-linked price database is <u>not</u> used, due to the absence of ICT resources. However, actual price information is used, but without a model-linked database;
- 10. A system and environmental analysis <u>is</u> carried out. This activity is used to map the building site, environment, stakeholders and the condition of the soil. This is done to reduce unforeseen costs resulting from the constraints from the system and the environment;
- 11. The model-linked database with policies and regulations is <u>not</u> used, due to the absence of ICT resources. Tests that help to prove that the product meets the conditions resulting from policies and regulations are carried out, for example the building decree test. But a model-linked database is not used to do this.

The *reason* for not applying the activities in container **1. Model** is that there is no integral 3D model available in the tender phase to carry out the calculation, verification, conflict control, building flow simulation and soil analysis based on the model. There is too little time available for modelling. However, DVBH does see the benefits of integral 3D modelling in the tender phase, such as insight into the complexity of the building and the interfaces. At the moment, other software such as Sketch-up or 2D software, is being used, but no or limited information can be linked to the model in this software. But, this information is required for calculation, verification and the building flow simulation. The calculation is still carried out by using and measuring from 2D drawings. Respondents state that this is beneficial for DVBH when implementing costs optimizations. With a 3D-model, this is more difficult. However, the respondents note that calculating with quantities exported from the model is faster and more accurate. The verification is largely performed by showing drawings to the client.

This is because there is little knowledge available about verification and validation and the requirements have not yet been converted into verification plans in the tender phase. Some respondents confuse verification and validation and think these activities are the same and about showing drawings to the client. However, they do note that this way of verification/validation is not sufficient anymore for UAC-IC projects. Besides this, there are no incentives in 2/4 projects to perform the verification, because the client does not value the verification process very much. The building flow simulation is also not carried out by DVBH because of a lack of time. But the respondents note that they see the benefits of this activity, such as early insight into the constraints of the construction site. At the moment the development of a building site plan and the calculation of the costs are based on 2D drawings. The BIM tools for soil analysis are not applied because the respondents do not know this activity and there are no suitable ICT resources available. Also, respondents think that a drilling test and a construction site analysis are sufficient for the analysis of the soil.

The *reason* for applying the activity in container **2. Solution** is that DVBH needs this activity to develop appropriate solutions for making a competitive price and design. After the tender phase, this activity helps to save costs and thus generate a profit margin. This is daily practice for DVBH.

The *reason* for partially applying the activity in container **3. Requirements** is that DVBH sees that UAC-IC contracts are becoming more and more popular and the verification of requirements becomes increasingly important. To be able to verify, she must convert the requirements into measurable specifications. However, DVBH has little knowledge of this process. She has started with a pilot (Unilever) to acquire knowledge, but according to the respondents this knowledge is not enough yet. Besides this, DVBH has already invested in ICT resources for the SE database, but has not invested in resources for linking the database with the 3D-model.

The *reason* for not applying the link with the databases in container **4. Information** is the lack of ICT resources. The respondents state that they use actual prices and information about policies and regulations, but do not store this information in a model-linked database. Respondents also think that it takes too much time to keep these databases up-to-date. However, the system and environmental analysis is being applied, and it helps DVBH to gain insight into the construction site, environment, stakeholders and condition of the soil and can therefore reduce unforeseen costs.

# 5. Part 3: Implementation proposal

This part of the paper will examine to which extent the combination of SE, BIM and MBSE activities can be implemented at DVBH (sub-question 3). The conclusions from part 1 and 2 are input for this chapter.

**Sub-question 3**: To which extent can the combination of SE, BIM and MBSE activities -that can improve the accuracy of the tender price of an UAC-IC project according to literature- be implemented at DVBH?

The table that is used in part 2 to examine the current situation at DVBH will be expanded, see Table 6 Method Part 3. First (1), a score about the impact of implementing a certain activity will be attached to the activities, based on information from the conceptual model (part 1). This score can be *low, medium* or *high*. Also, a score about the effort to implement an activity will be attached, based on the conclusions of the current situation analysis and confrontation. This score can be *easy, average* or *difficult*. The impact and effort will be plotted using an impact/effort matrix. The goal of this matrix is to determine which activities deserve the most attention during implementation. Only the activities that are not applied at DVBH or can be improved will be discussed. The activities that DVBH already applies well will be not further studied, because this is outside the scope of this paper. After the impact/effort matrix, (2) the interventions that can help DVBH with the implementation will be described. This part of the paper has not been investigated scientifically, but can provide guidelines for DVBH for further implementation.

TABLE 6 METHOD PART 3

PART 1:	CONCEPTUAL MODEL	PART 2: CURRENT SITUATION AND CONFRONTATION	PART 3: IMPLEMENTATION PROPOSAL	
Activity	Impact/improvements	Differences	Impact score	Effort score
Activity X.	Improvement accuracy and possible other	Differences between the expected pattern and observed pattern	Impact score ( <i>low, average</i> and	Effort score ( <i>easy,</i> average and
	improvements		high)	difficult)

# 5.1. Impact/effort matrix

This section will describe which activities, which are not yet or insufficiently applied at DVBH, should get the most attention during implementation. In order to determine this, an impact-effort matrix is used. This matrix describes which solutions (activities) can be most easily implemented and result in the most effect (Andersen, Fagerhaug, & Beltz, 2010). This is done by scoring the impact of an activity and the effort it takes to implement an activity. The matrix is presented in Figure 3 Impact/effort matrix and the full table in Appendix 3. Impact and Effort per activity. The results will be discussed in this section.



FIGURE 3 IMPACT/EFFORT MATRIX (BASED ON (ANDERSEN, FAGERHAUG, & BELTZ, 2010))

# 5.1.1. Do firstly

According to Figure 3 Impact/effort matrix the activities integral 3D modelling (1.4), link with SE database (3.1) and the conflict control (1.3) should be implemented first, and should receive most attention during implementation. These activities are in the green section of the figure. 3D modelling (1.4) has a high impact because it is a prerequisite for all other activities, especially the calculation. To be able to calculate based on the model, a model is required. And this model is not available in the tender phase at DVBH. In addition, modelling helps to create a more accurate design compared with 2D drawings, increasing the accuracy of the tender price. Besides, the advantage of this activity is that the skills and ICT resources for modelling are already present. However, a time investment is needed or a more efficient use of the available time. This requires extra attention for a process that allows quick steps to be taken in the short period of time. Prioritizing can help with this, see for example Figure 4 Example process.

In order to check the inconsistencies of the integral 3D-model, which is developed by different disciplines, the conflict control (1.3) is important. This activity has an average impact, because it helps to reduce errors and thus reduce failure costs, but is not a prerequisite for many other activities. This activity does not cost much effort to implement, because the ICT resources and skills are already available. However, a model is needed to carry out this activity. When the activity integral 3D modelling has been implemented, it will take little effort to implement the conflict control.

The link with the SE database (3.1) is also a prerequisite for many activities, such as the V&V and the building flow simulation. In addition, this activity is important for UAC-IC projects, because it is mandatory to prove if the requirements are met. For this purpose, the requirements must be measurable or verifiable. In addition, the activity helps to understand the requirements, thus enabling the contractor to develop a more appropriate solution, improving the accuracy of the tender price. However, like 3D modelling, this activity requires an investment in time. This makes the prioritization and parallel activities even more important, see for example Figure 4 Example process. There are already suitable ICT resources available at DVBH for the SE database (Relatics), but it is necessary to invest in ICT tools for linking the database with the integral 3D model. In addition, DVBH lacks skills for the requirements analysis, functional analysis and verification. This requires an investment. However, DVBH is already busy acquiring these skills by means of pilots (for example Unilever).

# 5.1.2. Do secondly

The orange section in Figure 3 Impact/effort matrix represents the activities that should be implemented later. The two most impactful activities are the V&V of the model (1.2) and the calculation based on the model (1.1). However, these activities also require the most effort. The verification can only be performed if there is an integral 3D-model and an SE database available. Once the first implementation has been finished (see 5.1.1. Do first), the SE database and a model are available. But an investment in ICT resources and skills is still needed. The validation can also be performed when the integral 3D-model is available. The impact of the V&V is high, because it helps to prove the quality standards and requirements are met. The activity therefore helps to improve accuracy.

The calculation based on the model (1.1) requires a lot of effort too. An integral 3D-model and a SE database are required, and the model must be verified and validated. In addition, 4D information must be present in the model to calculate labour and material costs. However, when the calculation is done based on the model, the accuracy can be dramatically improved, with a bias as low as +/- 3%. Because of this, the impact of this activity is high.

The third activity in the orange section is the building flow simulation (1.5). This activity has an average impact, because it helps to save costs by giving insight into the construction site and the activity is required to make a full calculation (including labour and material costs). However, the cost savings mainly consist of optimizations, which means that this activity does not have a high impact in comparison with other activities, such as the calculation based on the model. The advantage is that the ICT resources and skills for this activity are already present at DVBH. Still, a time investment is needed to carry out this activity. Again, prioritizing and parallel activities are important, see for example Figure 4 Example process.

# 5.1.3. Do not

The red area in Figure 3 Impact/effort matrix represents the activities that need not to be implemented (yet). The first are the BIM activities for soil analysis (1.6). The impact of this activity is low. The activity helps to gain insight in the soil, such as pipework, existing structures and the depth of the load-bearing layer. This helps to reduce unforeseen costs. But, just like the building flow simulation, these costs savings are mostly optimizations. The respondents also think that a soil drilling test and construction site analysis are sufficient to map the soil condition. In addition, there are no skills and ICT resources available, and a model of the soil of the construction site must be available. This makes implementation difficult.

The link with a price database (4.1) and a database with policies and regulations (4.3) also have a low impact. The price database helps to calculate (automatically) with current price information. However, the respondents indicate that they already do this, but without the use of a database. As a result, this activity has a low impact for DVBH. It is only automation. For checking policies and regulations, DVBH already uses tests, such as a building decree test, again without the use of a database. Therefore, this activity has a low impact too. In addition, both activities require an investment in ICT resources and a responsible person that maintains the databases. This results in an "average" effort score.

# 5.2. Interventions

In order to be able to apply the activities, a number of interventions are required. According to Caluwe and Vermaak (1999), interventions are "... one or a series of planned change activities aimed at enhancing the functioning and effectiveness of the organization (Kleijn & Rorink, 2012)" The following interventions can assist during implementation. These interventions have not been further investigated, but can provide guidelines for further implementation. The interventions are: (I) business process re-design, (II) training and coaching, (III) investment in activities, (IV) working in pilot projects and (V) management by speech.

# 5.2.1. Business process re-design

The limited time and capacity are an important limitation. To be able to apply a combination of SE, BIM and MBSE, a time investment is required for modelling and the requirement analysis. Because there is no extra time available, DVBH needs to deal more efficiently with the available time. This requires a review of the process for UAC-IC projects. Instead of successive activities (specification>design>calculation), activities in the process must run parallel. An example is shown in Figure 4 Example process. In this example, small packages will be

used. First, the requirements that have high priority for the first phase (draft design) have been specified. During this process, different people from the design, modelling and calculation team can assist with specifying the requirements. When this is finished, the specification process for the next phase starts, and the design team starts designing the draft (including verification). When the draft design is ready, modelling can start and after modelling calculation. When the model is used for the (automatic) calculation, less time is needed for calculating the costs and more time can be invested in the specification of the requirements, the design and modelling.

Specification	REQUIREMENTS draft design	REQUIREMENTS preliminary design			
Design	HELP WITH SPECIFICATION	REQUIREMENTS draft design	DESIGN preliminary design		
Modelling	HELP WITH SPECIFICATION	HELP WITH DESIGN/SPEC	DESIGN draft design	MODEL preliminary design	
Calculation	HELP WITH SPECIFICATION	HELP WITH DESIGN/SPEC	HELP WITH DESIGN/SPEC	CALCULATION	
	WEEK 1		WEEK 2	WEEK 3	

FIGURE 4 EXAMPLE PROCESS

# 5.2.2. Training and coaching

For different activities, training and coaching are required to implement the activity, namely for (I) *the calculation based on the model*, (II) *the verification and validation based on the model* and (III) *the requirement analysis*. For calculation, training is required to be able to calculate based on the model instead of drawings. So, the calculators no longer need to calculate by measuring quantities from drawings. They need to use the model for the calculation of quantities and costs. And the optimizations calculators develop must be done in the beginning of the process, when the specifications and the design are developed, see for example Figure 4 Example process. For verification, validation and the requirement analysis, training is required that teaches people how to convert customer demand into specifications and a suitable product.

# 5.2.3. Investment in ICT resources

Some activities require an investment in ICT resources. These activities are (I) the calculation based on the model, (II) verification based on the model and (III) the link with the SE database and model. Training and coaching is also required to teach DVBH how to work with these ICT resources

# 5.2.4. Pilot projects

To test the skills and application of the acquired ICT resources, pilot projects are required. A project is needed where one has the ability to "learn" new skills. An example is the Unilever project where a SE pilot has been conducted. The pilots can focus on different themes, namely (I) *setting up the SE database*, (II) *design and* modelling and (III) *V&V and calculation based on the model*.

# 5.2.5. Management by speech

The skills that the organization must acquire, especially the Systems Engineering skills, are new to the employees and different from the skills they are used to. Instead of thinking in solutions, employees need to think in requirements and solution-free specifications. These new skills and new knowledge can cause resistance. This requires appropriate management that focuses on convincing, guiding and supporting people. Management by Speech is an intervention where the managers operate close to the people. This management method focuses on interaction. Telling and motivating, but also asking questions is important (Kleijn & Rorink, 2012). As a result, the employees feel that they are seen and heard, so they are willing to do more for the organization during the implementation process.

# 6. Conclusion and recommendations

In this paper the extent to which a combination of SE, BIM and MBSE activities, which can improve the accuracy of the tender price for an UAC-IC project according to literature, is applied at DVBH has been investigated. In addition, the extent to which the (non-applied or insufficiently applied) activities can be implemented at DVBH is examined too. The answer to the main question can be divided into three parts: (1) how does a combination of SE, BIM and MBSE activities look like, (2) to what extent are the activities applied at DVBH and (3) to what extent can the activities be implemented at DVBH.

**Main question**: to which extent is a combination of SE, BIM and MBSE activities -that can improve the accuracy of the tender price of an UAC-IC project according to literature- applied at DVBH <u>and</u> to which extent can these activities be implemented at DVBH?

# 6.1. The combination of SE, BIM and MBSE

DVBH experiences an increasing popularity of UAC-IC contracts. In this type of contract, different phases of the project are performed by one contracting party. This means that the contractor is responsible for these phases. In addition, a UAC-IC contract has a number of contractual obligations. Firstly, the contractor is obliged to perform the project in accordance with the requirements arising from the contractual agreement (art. §1. paragraph 1, UAC-IC 2005). To be able to prove that the contractor carries out the work according to the requirements, it must prove that the quality conditions are being met by means of a quality assurance test (art. 19 UAC-IC 2005). In addition, the contractor must match the design with the soil condition (art. 13 UAC-IC 2005), and is responsible for the (financial) consequences when this is not done well. Finally, in an UAC-IC contract the tender price is fixed. This means that, after the project has been awarded to the contractor, the tender price cannot simply be changed and the contractor is responsible for the costs when the price is estimated too low.

For an UAC-IC contract, DVBH must develop both a design and a tender price. However, limited time is available (3-16 weeks). Due to the limited time and the fact that the tender budgets are tight and capacity cannot be increased, DVBH experiences difficulties in making a competitive design and an accurate tender price. For example, when DVBH discovers that certain requirements in the contract are not included in the design or overlooked, they are responsible for additional costs. Therefore, DVBH is curious to which extent a combination of SE and BIM can help to improve the accuracy of the tender price of an UAC-IC project. MBSE is described in literature as a possible combination, and can offer advantages for UAC-IC projects to prove that the quality standards and requirements are met. Therefore, this paper focused on "to which extent a combination of SE, BIM and MBSE activities can improve the accuracy of a tender price for a UAC-IC project, according to literature".

In order to improve the accuracy of the tender price of an UAC-IC project, literature proposes to carry out the calculation based on a model. By doing this, a price with a bias as low as +/- 3% can be determined. However, the conditions are that (I) an integral model needs to be developed that gives a good reflection of reality, (II) that the model reflects a solution that fits the client's scope, and expectations, (III) that both the model and the solution meet the contractual requirements and (IV) the restrictions resulting from the scope, applicable policies and regulations and other restrictive information. Various activities are therefore required:

# Model:

- 1. The *calculation* is based on an *integral model* with 4D information and current price information, whereby a tender price with a bias of +/- 3% can be calculated;
- 2. The integral model is *verified and validated* according to the requirements using a model-linked SE database, resulting in a model that complies with the customer demands;
- 3. The integral model, which contains information from different disciplines, should not conflict with each other, and therefore requires a *conflict control*. This reduces failure costs up to 10% of the contract value;
- 4. An *integral model* is developed by various disciplines, such as the contractor, architect, installation agencies, etc. As a result, the information on which the tender price is based becomes more accurate and the accuracy of the tender price will be improved. However, integral 3D modelling requires a time investment, while limited time is available. This asks for a more efficient use of the available time (see 8.);
- 5. *4D- information* will be added to the model, such as labour and equipment, so that labour and equipment costs can be calculated and insights can be obtained into the construction site. As a result, unforeseen costs can be reduced and the accuracy of the tender price can be improved;
- 6. The *condition of the soil* is taken into account by clashing the integral 3D-model with a soil model, reducing unforeseen costs due to soil constraints and improving the accuracy of the tender price.

# Solution:

7. A *trade study* is conducted to choose the best alternative that fits the requirements and other information, based on assessment criteria that arise from the requirements and other criteria such as feasibility, cost and time. The accuracy of the information on which the tender price is based, as well as the accuracy of the tender price itself improves.

# Requirements:

8. The model must be linked to a SE database to enable verification to be carried out. The SE database contains information about the requirements, functions and objects. To collect the information for the SE database a requirement analysis is conducted. This analysis consists of three steps: (I) identification of the requirements, (II) analysis and prioritization of the requirements and (III) translation of the requirements into measurable specifications (including functions). The requirement analysis takes time, so prioritization is needed (step II). Prioritizing helps to make small bundles of requirements instead of implementing them all at once. As a result, the implementation of requirements can be spread over time.

# Information:

- 9. The calculation must be based on current price information, by linking the model with a *price database* that is kept up-to-date centrally. Therefore, the accuracy of the tender prices improves;
- 10. The limitations resulting from the scope and the environment of the project should be mapped using a *system and environmental analysis* to highlight the constraints resulting from the scope, location, construction site, condition of the soil and stakeholders. This can reduce unforeseen costs and improve accuracy;
- 11. The model needs to fit the constraints of policies and regulations, by linking the model with a *database with policies and regulations*. This can reduce unforeseen costs caused by restricting policies and regulations and improve the accuracy of the tender price.

These activities help to improve the accuracy of the tender price and also help to meet the requirements of the UAC-IC contract, namely by conducting the quality assurance test and by aligning the project with the soil conditions. However, the activities and especially modelling and the requirement analysis require an investment in time. This is necessary because in earlier phases the costs can still be affected and changes do not result in lots of costs yet. As a result, an accurate product is developed at an early stage. Therefore, time and costs can be saved later on. However, because the time in the tender phase is limited and the tender budgets are tight, the available time must be used efficiently. Therefore, prioritizing the requirements, dividing the requirements in manageable packages and spreading the packages over the available time are important.

# 6.2. The application of SE, BIM and MBSE activities at DVBH

The application of the combination of SE, BIM and MBSE activities has been investigated at DVBH. From the analysis of the current situation and the confrontation with the conceptual model (the combination of SE, BIM and MBSE activities), can be concluded that the activities are not widely applied in the tender phase at DVBH. The following points can be concluded:

# Model:

- 1. The model is <u>not</u> used for calculation, due to the lack of an integral 3D-model in the tender phase. However, there are already ICT resources for the calculation of quantities available. The calculation is still performed manually by means of drawings and by measuring from these drawings.
- The model is <u>not</u> verified, due to the lack of a model, suitable ICT resources and skills. The verification is conducted (in 3/4 projects) by showing drawings to the client and (in 1/4 projects) by verifying the drawings using verification plans;
- 3. No conflict control <u>is</u> conducted, due to the lack of a model in the tender phase. After the tender phase a model is available, and the conflict control is performed. ICT resources and skills are available;
- Integral 3D modelling is <u>not</u> performed during the tender phase, but only after the tender phase. In the tender phase, there is too little time available for modelling. ICT resources and skills are available. In the tender phase, the design is developed by hand or using other resources, for example Sketch-Up;
- 5. The building flow simulation is <u>not</u> conducted, due to the lack of a model and time in the tender phase. After the tender phase, there is also a lack of time. However, ICT resources and skills are available;
- 6. The BIM tools for soil analysis are <u>not</u> carried out, due to the lack of a model of the soil, a 3D-model and appropriate ICT resources and skills. In addition, respondents think that a soil-drilling test and a construction site analysis are sufficient.

# Solution:

7. The trade study <u>is</u> used to be able to choose the most suitable alternative based on requirements and other assessment criteria. This helps to calculate a competitive price in the tender phase and save costs and generate a profit margin after the tender phase.

# **Requirements**:

8. There <u>are ICT</u> resources for the SE database available, but <u>no</u> resources for linking the database with the integral 3D-model. In 3/4 projects the requirements are only prioritized based on risk and in only one project based on the phase. In only one project the requirements are translated into measurable specifications. In the other projects, requirements are sorted based on risk or importance, and a suitable solution for the most important requirements is developed. No packages are developed that are spread over time and the activities do not run parallel.

# Information:

- 9. The model-linked price database is <u>not</u> used, due to the absence of ICT resources. However, actual price information is used, but without a model-linked database;
- 10. A system and environmental analysis <u>is</u> carried out. This activity is used to map the building site, environment, stakeholders and the condition of the soil. This is done to reduce unforeseen costs resulting from the constraints from the system and the environment;
- 11. The model-linked database with policies and regulations is <u>not</u> used, due to the absence of ICT resources. Tests that help to prove that the product meets the conditions resulting from policies and regulations are carried out, for example the building decree test. But a model-linked database is not used to do this.

The *reason* for not applying the activities in container **1. Model** is that there is no integral 3D model available in the tender phase to carry out the calculation, verification, conflict control, building flow simulation and soil analysis based on the model. There is too little time available for modelling. However, DVBH does see the benefits of integral 3D modelling in the tender phase, such as insight into the complexity of the building and the interfaces. At the moment, other software such as Sketch-up or 2D software, is being used, but no or limited information can be linked to the model in this software. But, this information is required for calculation, verification and the building flow simulation. The calculation is still carried out by using and measuring from 2D drawings. Respondents state that this is beneficial for DVBH when implementing costs optimizations. With a 3D-model, this is more difficult. However, the respondents note that calculating with quantities exported from the model is faster and more accurate. The verification is largely performed by showing drawings to the client.

This is because there is little knowledge available about verification and validation and the requirements have not yet been converted into verification plans in the tender phase. Some respondents confuse verification and validation and think these activities are the same and about showing drawings to the client. However, they do note that this way of verification/validation is not sufficient anymore for UAC-IC projects. Besides this, there are no incentives in 2/4 projects to perform the verification, because the client does not value the verification process very much. The building flow simulation is also not carried out by DVBH because of a lack of time. But the respondents note that they see the benefits of this activity, such as early insight into the constraints of the construction site. At the moment the development of a building site plan and the calculation of the costs are based on 2D drawings. The BIM tools for soil analysis are not applied because the respondents do not know this activity and there are no suitable ICT resources available. Also, respondents think that a drilling test and a construction site analysis are sufficient for the analysis of the soil.

The *reason* for applying the activity in container **2. Solution** is that DVBH needs this activity to develop appropriate solutions for making a competitive price and design. After the tender phase, this activity helps to save costs and thus generate a profit margin. This is daily practice for DVBH.

The *reason* for partially applying the activity in container **3. Requirements** is that DVBH sees that UAC-IC contracts are becoming more and more popular and the verification of requirements becomes increasingly important. To be able to verify, she must convert the requirements into measurable specifications. However, DVBH has little knowledge of this process. She has started with a pilot (Unilever) to acquire knowledge, but according to the respondents this knowledge is not enough yet. Besides this, DVBH has already invested in ICT resources for the SE database, but has not invested in resources for linking the database with the 3D-model.

The *reason* for not applying the link with the databases in container **4. Information** is the lack of ICT resources. The respondents state that they use actual prices and information about policies and regulations, but do not store this information in a model-linked database. Respondents also think that it takes too much time to keep these databases up-to-date. However, the system and environmental analysis is being applied, and it helps DVBH to gain insight into the construction site, environment, stakeholders and condition of the soil and can therefore reduce unforeseen costs.

# 6.3. Implementation proposal (recommendations)

A large part of the SE, BIM and MBSE activities are not yet applied at DVBH. To improve the accuracy of the tender price (according to literature), these activities can help. Using an impact-effort matrix, the activities that have the highest impact and require the least effort to implement the activity are being determined. The following points can be concluded from this:

- To do firstly: DVBH should first focus on developing the SE database and integral 3D modelling, including conflict control. The SE database is a prerequisite for activities such as the V&V. This verification is mandatory for an UAC-IC project and is required for making an accurate calculation. Because of this, developing the SE database has a high impact. 3D modelling is also a prerequisite for many activities, such as V&V, calculation and the building flow simulation. Without a model, these activities cannot be performed. In addition, modelling helps to create a more accurate model compared with 2D drawings, increasing the accuracy of the tender price. In order to check for inconsistencies in this model, which is drawn up by different disciplines, a conflict control is important. Up to 10% of the contract value can be saved with this conflict control. The advantage of these three activities is that most ICT resources are present, except for means for linking the SE database with the model. For the activities integral 3D modelling and the conflict control, skills are also already available. For the SE database, an investment in skills is still needed. Besides this, all three activities require a time investment, while only limited time is available. Because of this, an efficient division of time is important;
- To do secondly: When the 3D-model and the SE database are available, DVBH can implement the building flow simulation, V&V and the calculation based on the model. The building flow simulation is required for adding 4D information to the model, so that labour- and material costs can be calculated. In addition, this activity helps to reduce unforeseen costs resulting from the restrictions of the construction site. ICT resources and skills are already available. However, the activity requires an

investment in time, just like integral modelling. Again it is important to efficiently deal with time, which makes the prioritization and parallelization of activities important. The V&V has a high impact because it helps to prove the quality standards and requirements and results in a more accurate model and tender price. The calculation based on the model also has a high impact, because this activity improves the accuracy immediately with a bias as low as +/- 3%. However, for the V&V and calculation based on the model, the ICT resources and skills are not available. An investment in these resources and skills is needed;

• **Do not**: DVBH must not perform the soil analysis activities and the link with the databases with price information and policies and regulations (yet). The BIM tools for soil analysis have a low impact because the savings on unforeseen costs are only optimizations and respondents think that the soil-drilling test and an analysis of the construction site already provide a lot of insight into the soil. In addition, a model of the soil and suitable ICT resources are required, which are not available yet. The activities for linking databases with the model also have a low impact because DVBH already works with accurate price information and carries out policy and regulatory reviews (such as building decree test), but without a model-linked database. These databases also require an investment in ICT resources and a person who keeps the database up-to-date.

In order to implement the activities, a number of interventions are required. These interventions have not been further investigated, but can provide guidelines for DVBH for further implementation. The interventions are: (I) *business process re-design*, (II) *training and coaching*, (III) *investment in ICT resources*, (IV) *working in pilot projects* and (V) *management by speech*. The first intervention focuses on reorganizing the process for UAC-IC projects to be able to deal with the limited time and to develop the SE database and the model within this limited time range. The second intervention focuses on the acquisition of knowledge about calculation, verification and validation based on the model and the requirement analysis. The third intervention focuses on acquiring the missing ICT resources for model-based calculation, model-based verification and the connection between the SE database and the 3D-model. The fourth intervention focuses on applying the skills and ICT resources in a pilot project, so that DVBH can learn to apply the activities in practice. The fifth and final intervention focuses on convincing, guiding and supporting people, focusing on interaction. This helps to reduce resistance and facilitate implementation.

# 6.4. Contribution to literature and limitations

This paper contributes to scientific literature because a conceptual model has been developed, that describes which elements are needed to calculate an accurate tender price using a combination of SE, BIM and MBSE, according to literature. This conceptual model can be used to study practice. The paper contributes to the company's knowledge, because this paper describes how a combination of SE, BIM (and MBSE) can be applied at DVBH and which activities or processes DVBH has to focus on first.

An important limitation is that the paper is based on a conceptual and abstract model, based on the theory of Baker et al (2000) and Valdes et al (2016). Further research is needed to turn this abstract model in a more detailed model, using model development standards. This can increase the value of the conceptual model.

A second limitation of this research is that the accuracy of the tender price cannot be evaluated, and therefore it cannot be proved mathematically whether the application of the conceptual model actually results in an improved accuracy of the tender price. Further research is needed, that focuses on determining or calculating accuracy and whether the SE, BIM and MBSE activities actually improve accuracy.

In addition, this paper uses four cases to examine the application of the conceptual model. More cases can be examined to increase validity. Firstly, the cases in the past, which do not use SE or BIM, can be examined to see what goes wrong in these cases and how the combination of SE, BIM and MBSE can help to improve the results of the project. This can strengthen the value of the conceptual model. Besides this, the cases in the conducted case study happened to be success projects. One can also look to non-successful (loss-making) projects and examine if the combination of SE, BIM and MBSE contributes to this loss or not.

Also, the results from the case study and the conclusions from this paper cannot be generalized because only projects that are carried out by DVBH have been examined. In order to increase the generalisability (external validity), the application of the combination of SE, BIM and MBSE activities at different organizations should be investigated. Besides this, the application of the activities at the organisations of the partners of DVBH can be investigated, because partners also contribute to the model development and the calculation of an accurate tender price.

At last, further research is required to be able to implement the activities at DVBH. The implementation proposal described in this paper is limited to recommendations about which activities should be implemented first and which interventions can help with the implementation. But this has not been scientifically investigated. Further research is needed to develop a tailored implementation plan for DVBH.

# Acknowledgements

With this paper I complete my study "Construction Management and Engineering" at the University of Twente in Enschede. However, this research could not be completed without valuable assistance and guidance. Firstly, I would like to thank the counsellors from the University. Robin de Graaf for the excellent guidance and for giving new perspectives and insights when needed. Ruth Sloot for the excellent guidance and support for the BIM component of this research and research method. From the graduation company Dura Vermeer Bouw Hengelo, I would like to thank my supervisor Gert-Jan Ditsel for offering the opportunity to do this research, creating a sociable and educational environment and the great guidance throughout the entire research process. This also applies to my second supervisor Mark van der Meer, and his valuable insights, especially in Systems Engineering. Finally, I would like to thank the staff at Dura Vermeer for their time and the possibility to conduct the interviews. And I thank them for their interest, involvement and, in particular, the homey environment, in which I have been able to do my research with the greatest pleasure.

- everything is possible, the possible only hides behind the invisible -

# Glossary

Accuracy	the difference between the actual costs and budgeted costs (Dysert, 2006). Accuracy consists of two variables: bias and consistency (Skitmore, 1991)
Best Value Procurement (BvP)	a procurement method in which the client leaves the completion of the project to the contractor, because he/she is an expert and can therefore develop the best solution for the problem (source: interview)
Building Information Modelling	a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle from inception onward. A basic premise of BIM is collaboration by different stakeholders at different phases of the lifecycle of a facility to insert, extract, update, or modify information in the BIM to support and reflect the roles of that stakeholder (NBIMS, 2007)
Failure costs	All costs incurred unnecessarily for the final product. In each industry, failure costs are never completely avoided (de Vree, 2010)
Integrated contracts (UAC-IC)	a contract form where the design and construction phases, and possible other phases like maintenance finance and operations, are carried out by one party: the contractor (Wentzel, van Eekelen, Bone, Rip, & Bone, 2011)
Tender price	The price of the total cost of a project that is determined during the tender phase of a project (bron: interview)
Level of Development (LOD)	the extent to which the geometry of an object and its associated information has been devised (BIM Forum, 2016)
Model Based Systems Engineering	an approach to realising successful systems that is driven by a model that comprises a coherent and consistent set of representations that reflect multiple viewpoints in the system (Towers & Woodcock, 2015)
SMART	Specific, Measurable, Acceptable, Realistic and Time-bound
SysML	System Modeling Language is a graphical modeling language for specifying, analyzing, designing and verifying complex systems (OMG SysML)
Systems Engineering	an interdisciplinary approach and means to enable the realization of successful systems. Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs (Schreinemakers)
Tender	A procedure to obtain a particular service or product, by means of a tender (Tenderen.nl, sd)

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Appendix 1	. SE,	BIM	and	MBSE	activities
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Activity	Expected pattern	Impact/improvements	
	1. MODEL		
<u>1.1. Calculation based</u> on the model	Calculating the cost based on an integral 3D model results in a more accurate tender price. This is because a model is more accurate than 2D drawings (Ghaffarianhoseini, et al., 2016). It also saves the calculator time because they no longer need to quantify by hand, because it is done automatically (Autodesk, 2007). Conditions: (I) LOD 300/350, (II) model with 4D info, (III) fulfilling requirements and information/specifications, (IV) integral model, (V) actual price information, (VI) ICT resources, (VII) skills Pre-activities: 1.2/1.3/1.4/1.5/4.1	<ul> <li>Improving accuracy with a bias as low as +/-3% (Ghaffarianhoseini, et al., 2016)</li> <li>Time saving by reducing calculation time (Autodesk, 2007)</li> </ul>	
1.2. V&V of the model	The verification and validation of the model and its documentation results in a more accurate tender price by checking if the model meets the requirements. This improves the quality of the documentation and the tender price is based on more accurate information (Woodcock & Forder, 2012; Honour, 2004). <b>Conditions:</b> (I) SE database with verifiable requirements, (II) LOD300/350, (III) ICT resources, (IV) skills <b>Pre- activities:</b> 1.4/3.1	<ul> <li>Verified model that meets the requirements (Woodcock &amp; Forder, 2012; Honour, 2004).</li> <li>Activity for quality assurance (UAC-IC)</li> </ul>	
<u>1.3. Conflict control</u>	The conflict control results in a more accurate tender price by filtering errors in the model and models of other disciplines (Ghaffarianhoseini, et al., 2016). As a result, the cost price is based on more accurate information. With a conflict control, cost savings of 10% of the contract value can be achieved (Ghaffarianhoseini, et al., 2016). Conditions: (I) LOD350, (II) ICT resources, (III) skills Pre- activities: 1.4	<ul> <li>Improved accuracy by means of a reduction of costs (10% of the contract value) (Ghaffarianhoseini, et al., 2016)</li> <li>Improved model quality, because the model is more consistent (Azhar, Nadeem, Mok, &amp; Leung, 2008)</li> </ul>	
<u>1.4. Integral 3D</u> modelling	Integral 3D modelling results in a more accurate tender price, because the quality of the documentation is increased and the price is based on more accurate information. A 3D-model is more accurate than 2D drawings (Ghaffarianhoseini, et al., 2016). In addition, insight is gained into the complexity of the project using visualizations (Ghaffarianhoseini, et al., 2016). Changes can also be quickly implemented in the integral model, saving 7% of the total project time (Ghaffarianhoseini, et al., 2016). <b>Conditions</b> : (I) suitable solution, (II) LOD300/350, (III) prioritization, (IV) working together, (V) ICT resources, (VI) skills, (VII) organisational conditions <b>Pre- activities</b> : 2.1/3.1/4.3	<ul> <li>Improved accuracy, because a 3D-model is more accurate compared to 2D drawings (Ghaffarianhoseini, et al., 2016)</li> <li>Gaining insight into the model/product (Ghaffarianhoseini, et al., 2016)</li> <li>Quickly implement changes (Ghaffarianhoseini, et al., 2016)</li> <li>Time savings of 7% of the total project duration (Ghaffarianhoseini, et al., 2016)</li> </ul>	
<u>1.5. Building flow</u> simulation (4D BIM)	Building flow simulation (4D BIM) results in an accurate tender price by gaining insight into the constraints of the construction site (Chau, Anson, & Zhang, 2004), reducing unforeseen costs. Also construction and labour costs can be calculated based on the model. This model is more accurate than 2D drawings (Ghaffarianhoseini, et al., 2016).Conditions: (I) 3D-model with 4D info, (II) info restrictions construction site, (III) requirements regarding 4D-info, (IV) ICT resources, (V) skills, (VI) organisational conditionsPre- activities: 1.4/3.1/4.2	<ul> <li>Improved accuracy by reducing unforeseen costs and the calculation of labour and equipment costs based on the model (Ghaffarianhoseini, et al., 2016; Chau, Anson, &amp; Zhang, 2004)</li> <li>Gaining insight into the restrictions of the construction site (Chau, Anson, &amp; Zhang, 2004)</li> </ul>	

<u>1.6. BIM tools for soil</u> analysis	Using BIM tools for soil analysis results in a more accurate tender price by using (existing) soil models, which allows the design to fit the soil condition (Kessler, et al., 2015). This gives insight into the condition of the soil and can therefore reduce unforeseen costs. <b>Conditions</b> : (I) soil model, (II) integral 3D-model, (III) conflict control, (IV) ICT resources, (V) skills <b>Pre- activities</b> : 1.3/1.4	<ul> <li>Improved accuracy by reducing unforeseen costs</li> <li>Gaining insight in the condition of the soil (Kessler, et al., 2015). This activity helps to meet the requirement of the UAC-IC contract (art. §13 UAC-IC 2005).</li> </ul>
	2. SOLUTION/DESIGN	
2.1. Trade study	The trade study contributes (indirectly) to a more accurate tender price by choosing an appropriate solution that meets the requirements and other criteria (Office of Engineering and Construction Management, 2003). Conditions: (I) alternatives, (II) assessment criteria, (III) skills	<ul> <li>Improving accuracy by developing a more suitable solution (Office of Engineering and Construction Management, 2003)</li> <li>Transparent choice-making process (Department of Defense, 2001)</li> </ul>
	3. REQUIREMENTS	
<u>3.1. Link SE database</u> <u>with model</u>	The link with the SE database contributes indirectly to a more accurate tender price, because the database specifies the conditions or specifications the product has to meet. As a result, a better solution and model can be developed, and can be (automatically) verified based on the requirements in the database. In addition, the database provides insight into the requirements and specifications, and the information is in one place and linked to each-other.  Conditions: (I) functions, (II) objects, (III) requirements, (IV) information, (V) ICT resources, (VII) skills, (VIII) organisational conditions  Pre- activities: 4.2.	<ul> <li>Improving accuracy by specifying the performance of the most suitable solution (Dori, 2016)</li> <li>Gaining insight in the requirements and specifications</li> <li>Structured information, all in one place</li> <li>Input for automatic verification (Valdes, 2016; Baker, et al., 2000; Polit-Casillas &amp; Howe, 2013)</li> </ul>
	2. INFORMATION	
4.1. Link model with price database	Linking the model with a price database results in an accurate tender price, by using actual price information (Liu & Zhu, 2007). Conditions: (I) ICT resources, (II) keep database up-to-date, (III) available price information	<ul> <li>Improving accuracy by using actual price information (Liu &amp; Zhu, 2007)</li> </ul>
4.2. System and environmental analysis	The system and environmental analysis results in an accurate tender price by reducing unforeseen costs by gaining insight into the scope, system, environment and condition of the soil. Conditions: (I) skills	<ul> <li>Improving accuracy by reducing unforeseen costs</li> <li>Gaining insight in the scope, system, environment and condition of the soil (de Graaf, 2014)</li> </ul>
4.3. Link model with database policies and regulations	Linking the model with a policy and regulation database results in an accurate tender price by reducing unforeseen costs caused by policies and regulations (Valdes, 2016). <b>Conditions:</b> (I) ICT resources, (II) keep database up-to-date	<ul> <li>Improving accuracy by reducing unforeseen costs (Valdes, 2016)</li> </ul>

THEATER WERELD VAN ONTMOETING						
Activity	Expected pattern	Observed pattern	Examples	Similarities and differences		
		1. MODEL				
<u>1.1. Calculation based</u> on the model	Calculating the cost based on an integral 3D model results in a more accurate tender price. This is because a model is more accurate than 2D drawings (Ghaffarianhoseini, et al., 2016). It also saves the calculator time because they no longer need to quantify by hand, because it is done automatically (Autodesk, 2007).	The model is not used for calculation because the model was not released by the architect and there is not enough time to set up a model with the required (preliminary design) level in both the tender phase and after the tender phase. As a result, no calculation can be made based on the model. The calculation is made using (2D) drawings. There are no suitable ICT resources available for the automatic calculation	"The BIM model was not used for calculation the architect did not want to release the design and it was not on the right (LOD) level" "There is not enough time to calculate based on the model"	<ul> <li><u>Application:</u> Not applied</li> <li><u>Conditions</u>:         <ul> <li>(I) no LOD300/350</li> <li>(II) no 4D info</li> <li>(III) no verification of the model</li> <li>(IV) no integral modelling during tender phase, only after tender phase</li> <li>(V) no link with a price database</li> <li>(VI) ICT resources not available</li> <li>(VII) skills not available, calculation is done by hand</li> </ul> </li> <li><u>Pre-activities</u>: 1.2/1.3/1.4/1.5/4.1</li> </ul>		
1.2. V&V of the model	The verification and validation of the model and its documentation results in a more accurate tender price by checking if the model meets the requirements. This improves the quality of the documentation and the tender price is based on more accurate information (Woodcock & Forder, 2012; Honour, 2004).	Verification is carried out by letting the client check the drawings.The model is not used because it is not available in the tender phase. There are also no suitable ICT resources and skills available to carry out the verification based on the model * The respondents mix up the terms verification and validation	"We let the client check the work (the drawings)" "We have involved the customer in the process by showing the work"	<ul> <li><u>Application:</u> Verification and validation by showing drawings to the client</li> <li><u>Conditions</u>:         <ul> <li>(I) no SE database</li> <li>(II) no LOD300/350</li> <li>(III) ICT resources not available</li> <li>(IV) no skills for verification based on model</li> </ul> </li> <li><u>Pre-activities</u>:         <ul> <li>1.4/3.1</li> </ul> </li> </ul>		
1.3. Conflict control	The conflict control results in a more accurate tender price by filtering errors in the model and	A conflict control is only carried out after the tender phase to	"We have used BIM and clashed the model to see if the model is	<ul> <li><u>Application</u>: Not in the tender phase,</li> </ul>		

# Appendix 2. Application of SE, BIM and MBSE activities

	models of other disciplines (Ghaffarianhoseini, et al., 2016). As a result, the cost price is based on more accurate information. With a conflict control, cost savings of 10% of the contract value can be achieved (Ghaffarianhoseini, et al., 2016).	check if the model, prepared by different parties, is correct. This improves the quality of the model and the respondents suspect a reduction of failure costs. In the tender phase there is no model for conducting the conflict control	correct (after the tender phase)" "I think the conflict control helps to reduce failure costs"	but after the tender phase. Conditions: (I) no LOD350 in tender phase, but only after tender phase (II) ICT resources available (III) skills available Pre-activities: 1.4
<u>1.4. Integral 3D</u> modelling	Integral 3D modelling results in a more accurate tender price, because the quality of the documentation is increased and the price is based on more accurate information. A 3D-model is more accurate than 2D drawings (Ghaffarianhoseini, et al., 2016). In addition, insight is gained into the complexity of the project using visualizations (Ghaffarianhoseini, et al., 2016). Changes can also be quickly implemented in the integral model, saving 7% of the total project time (Ghaffarianhoseini, et al., 2016).	In the tender phase, this activity has not been used, due to lack of time. After the tender phase, the activity has been used. Due to the complexity of the project, the use of BIM was indispensable. In addition, other parties, such as the manufacturer, also work with BIM so DVBH is stimulated to do so too. The application of BIM provides insight into the building, improves the quality of the drawings, and helps to reduce failure costs	"Due to the circular forms and complexity of the theater, we needed BIM to make the drawings we have done this together with the architect, constructor and subcontractors" "The constructor only works in 3D nowadays, so we should do this too" "We use BIM to gain insight into the building and make good drawings. An example is a line-of- sight simulation for determining the height of the balustrade " "BIM required time but then you have better control of the process, due to the time we do not use it in the tender phase, only after it would be a waste if you put a lot of time in the model and you do not win the project " "With BIM there are fewer failure costs. This is worth the time- investment"	<ul> <li><u>Application</u>: Not applied in the tender phase, only after the tenderphase</li> <li><u>Conditions</u>: (I) suitable solution available (II) no LOD300/350 in tender phase, only after tender phase (III) prioritization based on risks, but not on other criteria (IV) integral cooperation in the model only after tender phase (V) ICT resources available (VI) skills available</li> <li><u>Pre-activities</u>: 2.1/3.1/4.3</li> </ul>
1.5. Building flow	Building flow simulation (4D BIM) results in an	At DVBH there is ambition to	"We did have the ambition to	<u>Application</u> :
simulation (4D BIM)	accurate tender price by gaining insight into the	model in 4D, but not the time. In	model in 4D, but we did not have	Not applied
	constraints of the construction site (Chau, Anson,	both the tender phase and after	the time"	<u>Conditions</u> :
	& Zhang, 2004), reducing unforeseen costs. Also	the tender phase, this activity is	"4D can help to gain insight into	(I) no model with 4D info
	construction and labour costs can be calculated	not applied due to lack of time.	how everything goes on the	(II) information about

	based on the model. This model is more accurate than 2D drawings (Ghaffarianhoseini, et al., 2016).	However, skills and ICT resources are available. The respondents also think that the activity can help to understand the flows on the construction site	building site" "4D modelling is only performed after awarding the project, when there is a model available"	restrictions of the construction site available (III) requirements about site and planning are partly available (IV) ICT resources available (V) skills available Pre-activities: 1.4/3.1/4.2
<u>1.6. BIM tools for soil</u> analysis	Using BIM tools for soil analysis results in a more accurate tender price by using (existing) soil models, which allows the design to fit the soil condition (Kessler, et al., 2015). This gives insight into the condition of the soil and can therefore reduce unforeseen costs.	At DVBH there are no ICT resources and knowledge available to apply this activity. In addition, the respondents think that the soil can already be adequately mapped by means of a soil-drilling test and a construction site analysis	"We have no resources for this activity" "I do not know this activity" "We use existing drawings and go to the building site" "we used a soil-drilling test"	<ul> <li><u>Application</u>: Not applied</li> <li><u>Conditions</u>: (I) no model of the soil available (II) no integral 3D-model available (III) no conflict control (IV) no ICT resources available (V) no skills available</li> <li><u>Pre-activities</u>: 1.3/1.4</li> </ul>
	•	2. SOLUTION	•	
2.1. Trade study	The trade study contributes (indirectly) to a more accurate tender price by choosing an appropriate solution that meets the requirements and other criteria (Office of Engineering and Construction Management, 2003).	Alternatives are developed to optimize design and create cost savings. The alternatives are weighed by looking at the requirements and other criteria (feasibility, cost, time). Alternatives are developed in the tender phase, to make a competitive costs calculation. After the tender phase, this will be done to create a profit margin. It can help to improve accuracy by thinking about smart solutions that can save costs	"Because of the BvP procedure we need to think about alternatives because we have to deliver ideas about the aesthetics of the building" "We made alternatives for the roof and facade because we had to stay within budget" "By making alternatives we were able to provide more volume for the client. He was happy with that"	<ul> <li><u>Application</u>: Applied</li> <li><u>Conditions</u>:         <ul> <li>(I) alternatives are developed</li> <li>(II) requirements and other variables are used as criteria</li> <li>(III) skills available</li> </ul> </li> </ul>

		3. REQUIREMENTS		
<u>3.1. Link SE database</u> <u>with model</u>	The link with the SE database contributes indirectly to a more accurate tender price, because the database specifies the conditions or specifications the product has to meet. As a result, a better solution and model can be developed, and can be (automatically) verified based on the requirements in the database. In addition, the database provides insight into the requirements and specifications, and the information is in one place and linked to each- other.	Due to the BvP procedure, little attention has been paid to the specification of the project. The requirements are solely prioritized based on risk. There is also no use of a model- linked SE database. There are no ICT resources available	"because of the BvP procedure there were not many requirements. The requirements were processed in the impressions provided" "The analysis of the requirements has been carried out in a timely manner. We first read the requirements and outlined the most risky requirements and developed solutions " "The benefits of SE are not really clear I think it helps to create an overview of the requirements, but that was not really necessary for this project." "This was a UAV-GC light project. We did not have to provide a detailed (verification) plan"	<ul> <li>Application: Not applied</li> <li><u>Conditions</u>:         <ul> <li>(1) no functions described</li> <li>(II) no objects described</li> <li>(III) no requirements in database, these are also not measurable</li> <li>(IV) no info in database.</li> <li>System and environment have been analysed though</li> <li>(V) no ICT resources available</li> <li>(VII) no skills available</li> </ul> </li> <li><u>Pre-activities</u>: 4.2</li> </ul>
		4. INFORMATION		
4.1. Link model with price database	Linking the model with a price database results in an accurate tender price, by using actual price information (Liu & Zhu, 2007).	The price database that is linked to the model has not been used during the tender phase. No suitable ICT resources are available.	"We only use Kental. This allows you to determine a price based on key figures. For this you need to know some project characteristics" "With Kental we can determine a price and see if it's feasible to carry on with the project or not"	<ul> <li><u>Application</u>: Not applied</li> <li><u>Conditions</u>: (I) no ICT resources available (II) no database that is kept up-to-date (III) no database, but prices are available</li> </ul>
4.2. System and environmental analysis	The system and environmental analysis results in an accurate tender price by reducing unforeseen costs by gaining insight into the scope, system, environment and condition of the soil.	At DVBH, an analysis was carried out to inquire information about the construction site and the environment and a stakeholder analysis was conducted. In addition, a soil-drilling test was performed to determine the condition of the soil.This helps to reduce unforeseen costs and improve accuracy.	"We saw (in time) that the construction site was enclosed by other construction sites on both sides if we had not seen this we would have had extra costs" "The customer department often makes a stakeholder analysis of the direct and indirect stakeholders" "Because of the election of a new	<ul> <li><u>Application</u>: Applied</li> <li><u>Conditions</u>: (I) skills available</li> </ul>

			political party who was against the project, we risked the project being terminated" "We perform a soil-drilling test to		
			determine the condition of the soil"		
4.3. Link model with	Linking the model with a policy and regulation	At DVBH, this activity has not been	"We do not have the means for	•	Application:
database policies and	database results in an accurate tender price by	performed due to the lack of ICT	that"		Not applied
regulations	reducing unforeseen costs caused by policies and	resources and the time it takes to	"That seems to be a lot of work to	•	Conditions:
	regulations (Valdes, 2016).	manage the database. Policies and	keep the databse up-to-date. Who		(I) no ICT resources
		regulations, such as the building	will do that?"		available
		decree, are being tested	"We have carried out a building		(II) no database that is
		separately	decree test"		kept up-to-date

		C-SMART				
Activity	Expected pattern	Observed pattern	Examples	Similarities and differences		
	1. MODEL					
<u>1.1. Calculation based</u> on the model	Calculating the cost based on an integral 3D model results in a more accurate tender price. This is because a model is more accurate than 2D drawings (Ghaffarianhoseini, et al., 2016). It also saves the calculator time because they no longer need to quantify by hand, because it is done automatically (Autodesk, 2007).	During the tender phase, this activity has not been conducted because of the lack of a model and time. After the tender phase, some quantities have been exported from the model which are used for the calculation. According to the respondents, this improves the accuracy. However, for some departments, such as ABK , the model is not available in time after the tender phase to make a calculation. Without the model, the costs are determined based on drawings and sketches	"We limitedly used the model. We have exported some quantities to determine the price. The advantage is that the model is better than 2D drawings and that is good for the calculation " "The BIM model is finished too late for the ABK office. " "The (ABK) costs are determined on the basis of drawings and sketches"	<ul> <li><u>Application:</u> Not applied</li> <li><u>Conditions:</u> (I) no LOD300/350 (II) no 4D info (III) no verification of the model (IV) no integral modelling during tender phase, only after tender phase (V) no link with a price database (VI) ICT resources for exporting quantities available (VII) skills available, but calculation is done by hand</li> <li><u>Pre-activities:</u> 1.2/1.3/1.4/1.5/4.1</li> </ul>		
1.2. V&V of the model	The verification and validation of the model and its documentation results in a more accurate	During and after the tender phase, the drawings are verified by	"We have checked the drawings using a drawing procedure	• <u>Application:</u> Verification and		

	tender price by checking if the model meets the requirements. This improves the quality of the documentation and the tender price is based on more accurate information (Woodcock & Forder, 2012; Honour, 2004).	showing them to the client by following a drawing procedure scheme. The model is not used for this. The model is not developed at the desired level, there are no SE database and no appropriate ICT resources	scheme"	<ul> <li>validation by showing drawings to the client</li> <li><u>Conditions</u>: <ul> <li>(I) no SE database</li> <li>(II) no LOD300/350</li> <li>(III) ICT resources not available</li> <li>(IV) no skills for verification based on model</li> </ul> </li> <li><u>Pre-activities</u>: <ul> <li>1.4/3.1</li> </ul> </li> </ul>
<u>1.3. Conflict control</u>	The conflict control results in a more accurate tender price by filtering errors in the model and models of other disciplines (Ghaffarianhoseini, et al., 2016). As a result, the cost price is based on more accurate information. With a conflict control, cost savings of 10% of the contract value can be achieved (Ghaffarianhoseini, et al., 2016).	During the tender phase, no conflict control is performed due to the lack of a model. This will be done after the tender phase. The respondents indicate that this activity improves the quality of the documentation	"We made (after the tender phase) a performance model and clashed it" "Because of the inexperience of some parties, the clash control was very important to deliver a good model"	<ul> <li><u>Application</u>: Not in the tender phase, but after the tender phase.</li> <li><u>Conditions</u>: (I) no LOD350 in tender phase, but available after tender phase (II) ICT resources available (III) skills available</li> <li><u>Pre-activities</u>: 1.4</li> </ul>
<u>1.4. Integral 3D</u> modelling	Integral 3D modelling results in a more accurate tender price, because the quality of the documentation is increased and the price is based on more accurate information. A 3D-model is more accurate than 2D drawings (Ghaffarianhoseini, et al., 2016). In addition, insight is gained into the complexity of the project using visualizations (Ghaffarianhoseini, et al., 2016). Changes can also be quickly implemented in the integral model, saving 7% of the total project time (Ghaffarianhoseini, et al., 2016).	The activity was not applied in the tender phase due to a lack of time. After the tender phase, integral modelling was used as a pilot to gain insight into the building and make detailed drawings. Because it was a pilot, it was difficult for the external partners of DVBH to work in the model.	"The customer did not ask for BIM but we used it as a pilot" "We have used BIM to get insight into the building and to be able to make good drawings" "BIM will only be applied after the tender phase, because in the tender phase there is not enough time to set up everything" "By using BIM we could deal the limited space for the installations more easily and we could fit in the installations exactly" "Because it was a pilot, it was difficult for installers and	<ul> <li><u>Application</u>: Not applied in the tender phase, only after the tenderphase</li> <li><u>Conditions</u>: (I) suitable solution available (II) no LOD300/350 in tender phase, only after tender phase (III) prioritization based on risks, but not on other criteria (IV) integral cooperation in the model only after</li> </ul>

1.5. Building flow simulation (4D BIM)	Building flow simulation (4D BIM) results in an accurate tender price by gaining insight into the	For this project this activity has not been performed due to a lack of	subcontractors to work in BIM. Because of this inexperience, extra engineering was needed. This also had an effect on the calculation " "The ABK actually has no experience with 3D BIM and the calculation also " "We have not applied 4D modelling, this takes too much	tender phase         (V) ICT resources         available         (VI) skills available         • Pre-activities:         2.1/3.1/4.3         • Application:         Not applied
	constraints of the construction site (Chau, Anson, & Zhang, 2004), reducing unforeseen costs. Also construction and labour costs can be calculated based on the model. This model is more accurate than 2D drawings (Ghaffarianhoseini, et al., 2016).	time.	time"	<ul> <li><u>Conditions</u>:         <ul> <li>(I) no model with 4D info</li> <li>(II) information about restrictions of the construction site available</li> <li>(III) requirements about site and planning partly available</li> <li>(IV) ICT resources available</li> <li>(V) skills available</li> </ul> </li> <li>Pre-activities:         <ul> <li>1.4/3.1/4.2</li> </ul> </li> </ul>
<u>1.6. BIM tools for soil</u> <u>analysis</u>	Using BIM tools for soil analysis results in a more accurate tender price by using (existing) soil models, which allows the design to fit the soil condition (Kessler, et al., 2015). This gives insight into the condition of the soil and can therefore reduce unforeseen costs.	This activity is not used, because none of the respondents knows this activity and there are no ICT resources and skills available. Also the soil-drilling test and the construction site analysis are used for analysing the soil.	"I do not really know that activity" "I've heard of that, but we do not do that" "We are conducting a soil-drilling test and a construction site analysis"	<ul> <li><u>Application</u>: Not applied</li> <li><u>Conditions</u>: (I) no model of the soil available (II) no integral 3D-model available (III) no conflict control (IV) no ICT resources available (V) no skills available</li> <li><u>Pre-activities</u>: 1.3/1.4</li> </ul>
		2. SOLUTION		
2.1. Trade study	The trade study contributes (indirectly) to a more accurate tender price by choosing an appropriate solution that meets the requirements and other	Alternatives are developed to optimize design and create cost savings. The alternatives are	"Depending on the freedom we have, we make choices and consider several options that suits	<ul> <li><u>Application</u>: Applied</li> <li>Conditions:</li> </ul>

	criteria (Office of Engineering and Construction Management, 2003).	weighed by looking at the requirements and other criteria (feasibility, cost, time). Alternatives are developed in the tender phase, to make a competitive costs calculation. After the tender phase, this will be done to create a profit margin. It can help to improve accuracy by thinking about smart solutions that can save costs	best" "We make alternatives to save money. And for making profit "	(I) alternatives are developed (II) requirements and other variables are used as criteria (III) skills available
	•	3. REQUIREMENTS	•	
3.1. Link SE database with model	The link with the SE database contributes indirectly to a more accurate tender price, because the database specifies the conditions or specifications the product has to meet. As a result, a better solution and model can be developed, and can be (automatically) verified based on the requirements in the database. In addition, the database provides insight into the requirements and specifications, and the information is in one place and linked to each- other.	Systems Engineering was not yet known during the project. So this activity is not applied. According to the respondents, it would take too much time. The requirements are prioritized based on importance and then an appropriate solution is developed. There are also no ICT resources available to manage the requirements and to link the database with the model	"No, we were not really familiar with the UAC-IC at all and not at all with SE we thought SE would cost us more time than it would save us" "We read the requirements and looked which ones are the most important"	<ul> <li><u>Application</u>: Not applied</li> <li><u>Conditions</u>: (I) no functions described (II) no objects described (III) no requirements in database, these are also not measurable (IV) no info in database. System and environment have been analysed (V) no ICT resources available (VII) no skills available</li> <li><u>Pre-activities</u>: 4.2</li> </ul>
		4. INFORMATION		
<u>4.1. Link model with</u> price database	Linking the model with a price database results in an accurate tender price, by using actual price information (Liu & Zhu, 2007).	There is no use of a price database that is linked to the model during the tender phase, because there are no ICT resources available.	"We only use Kental. This allows you to determine a price based on key figures. For this you need to know some project characteristics" "With Kental we can determine a price and see if it's feasible to carry on with the project or not"	<ul> <li>Application: Not applied</li> <li><u>Conditions</u>: (I) no ICT resources available (II) no database that is kept up-to-date (III) no database, but prices available</li> </ul>
4.2. System and	The system and environmental analysis results in	An analysis of the construction	"We looked at the building site and	<ul> <li><u>Application</u>:</li> </ul>

environmental analysis	an accurate tender price by reducing unforeseen costs by gaining insight into the scope, system, environment and condition of the soil.	site, the environment and the soil (soil-drilling test) has been carried out in this project.	how it fits the environment" "We have made a soil-drilling test and a construction site analysis"	Applied <ul> <li><u>Conditions</u>:</li> <li>(I) skills available</li> </ul>
4.3. Link model with database policies and regulations	Linking the model with a policy and regulation database results in an accurate tender price by reducing unforeseen costs caused by policies and regulations (Valdes, 2016).	In this project a database of policies and regulations are not used due to the lack of ICT resources. Policies and regulations, such as the building decree test, are being tested (separately)	"No, we will not do that" "We often conduct a building decree test"	<ul> <li><u>Application</u>: Not applied</li> <li><u>Conditions</u>: (I) no ICT resources available (II) no database that is kept up-to-date</li> </ul>

	Unilever				
Activity	Expected pattern	Observed pattern	Examples	Similarities and differences	
		1. MODEL			
<u>1.1. Calculation based</u> on the model	Calculating the cost based on an integral 3D model results in a more accurate tender price. This is because a model is more accurate than 2D drawings (Ghaffarianhoseini, et al., 2016). It also saves the calculator time because they no longer need to quantify by hand, because it is done automatically (Autodesk, 2007).	The project is still in the tender phase. In the tender phase, no BIM model has been developed and is not used for calculation, due to the limited time. The drawings of the architect have been used for the calculation. For the calculators, the drawings are easier than a model, because they make optimizations to save costs. This may be more difficult in a 3D-model, because the calculations department has little knowledge of BIM	"We have not used BIM yet" "When the model has been developed, we have already bought everything" "The architect's drawings are priced we can also think about optimizations. This is more difficult with a model "	<ul> <li><u>Application:</u> Not applied</li> <li><u>Conditions</u>:         <ul> <li>(I) no LOD300/350</li> <li>(II) no 4D info</li> <li>(III) no verification of the model</li> <li>(IV) no integral modelling during tender phase</li> <li>(V) no link with a price database</li> <li>(VI) ICT resources not available</li> <li>(VII) skills not available, calculation is done by hand</li> </ul> </li> <li><u>Pre-activities</u>:         <ul> <li>1.2/1.3/1.4/1.5/4.1</li> </ul> </li> </ul>	
1.2. V&V of the model	The verification and validation of the model and its documentation results in a more accurate tender price by checking if the model meets the requirements. This improves the quality of the documentation and the tender price is based on more accurate information (Woodcock & Forder, 2012; Honour, 2004).	No verification plans have been made during the tender phase and no model is available. One wants to conduct the V&V after the tender phase and also check the model, but not by means of an automatic plug-in because the	"We have not used BIM yet" "We intend to make a verification plan and check the model, but not directly by means of a plug-in or so we tried this for LOA, but this did not go as expected"	<ul> <li><u>Application:</u> Verification and validation by showing drawings to the client</li> <li><u>Conditions</u>:         <ul> <li>(I) SE database available</li> <li>(II) no LOD300/350</li> </ul> </li> </ul>	

1.3. Conflict control	The conflict control results in a more accurate tender price by filtering errors in the model and models of other disciplines (Ghaffarianhoseini, et al., 2016). As a result, the cost price is based on more accurate information. With a conflict control, cost savings of 10% of the contract value can be achieved (Ghaffarianhoseini, et al., 2016).	known plug-in was not suitable. The verification will be done manually. There is a SE database (Relatics) that contains the requirements, but it is not linked to the model No BIM model has yet been developed and no conflict control has been carried out. It is planned to do this after the tender phase. The respondents state that it helps to solve problems in the model	"We have not used BIM yet" "We're going to clash it helps solve problems in the model"	<ul> <li>(III) ICT resources not available</li> <li>(IV) no skills for verification based on model</li> <li><u>Pre-activities</u>: 1.4/3.1</li> <li><u>Application</u>: Not applied</li> <li><u>Conditions</u>: (I) no LOD350 in tender phase</li> <li>(II) ICT resources available</li> <li>(III) skills available</li> <li><u>Pre-activities</u>:</li> </ul>
<u>1.4. Integral 3D</u> modelling	Integral 3D modelling results in a more accurate tender price, because the quality of the documentation is increased and the price is based on more accurate information. A 3D-model is more accurate than 2D drawings (Ghaffarianhoseini, et al., 2016). In addition, insight is gained into the complexity of the project using visualizations (Ghaffarianhoseini, et al., 2016). Changes can also be quickly implemented in the integral model, saving 7% of the total project time (Ghaffarianhoseini, et al., 2016).	During the tender phase no model has been developed due to the lack of time and the fact that there are many changes that take a lot of time to implement in the model. However, partly because BIM is required for this project, it will be applied after the tender phase. Also, most projects are already being developed in BIM at DVBH, which is an incentive to make the model. The respondents indicate that the failure costs will be reduced, when BIM is used. They don't know exactly how much costs are saved.	"We have not used BIM yet, we will only do this after the tender phase" "In the tender phase, we do not use BIM because there is little time and there are many changes. It also takes time to make changes in the model " "I think BIM was also required for this project, so we're going to use it after the tender phase" "BIM is always used (after the tender phase)" "BIM can help to save failure costs"	<ul> <li>1.4</li> <li>Application: Not applied in the tender phase</li> <li>Conditions: <ul> <li>(I) suitable solution available</li> <li>(II) no LOD300/350 in tender phase, only after tender phase</li> <li>(III) prioritization based on risks, but not on other criteria</li> <li>(IV) integral cooperation in the model only after tender phase</li> <li>(V) ICT resources available</li> <li>(VI) skills available</li> </ul> </li> <li>Pre-activities: 2.1/3.1/4.3</li> </ul>
<u>1.5. Building flow</u> simulation (4D BIM)	Building flow simulation (4D BIM) results in an accurate tender price by gaining insight into the	Due to the fact that this project has just been awarded, there is no	"We have not used BIM yet" "maybe later"	<u>Application:</u> Not applied

	constraints of the construction site (Chau, Anson, & Zhang, 2004), reducing unforeseen costs. Also construction and labour costs can be calculated based on the model. This model is more accurate than 2D drawings (Ghaffarianhoseini, et al., 2016).	model available yet and no simulations have been made. In the tender phase there is no time for this, maybe this activity will be conducted after the tender phase.	"In the tender phase there is no time for BIM"	<ul> <li><u>Conditions</u>:         <ul> <li>(I) no model with 4D info</li> <li>(II) information about restrictions of the construction site available</li> <li>(III) requirements about site and planning partly available</li> <li>(IV) ICT resources available</li> <li>(V) skills available</li> </ul> </li> <li>Pre-activities: 1.4/3.1/4.2</li> </ul>
<u>1.6. BIM tools for soil</u> analysis	Using BIM tools for soil analysis results in a more accurate tender price by using (existing) soil models, which allows the design to fit the soil condition (Kessler, et al., 2015). This gives insight into the condition of the soil and can therefore reduce unforeseen costs.	The respondents are not very familiar with this activity, and ICT resources are lacking. So this activity has not been conducted. The respondents note that a soil- drilling test and a construction site analysis are already sufficient.	"We did not use this" "I do not know that" "We have not used BIM yet" "We are doing a soil-drilling tesst" "Information is gathered about cables and pipelines"	<ul> <li><u>Application</u>: Not applied</li> <li><u>Conditions</u>: (I) no model of the soil available (II) no integral 3D-model available (III) no conflict control (IV) no ICT resources available (V) no skills available</li> <li><u>Pre-activities</u>: 1.3/1.4</li> </ul>
		2. SOLUTION	•	
2.1. Trade study	The trade study contributes (indirectly) to a more accurate tender price by choosing an appropriate solution that meets the requirements and other criteria (Office of Engineering and Construction Management, 2003).	Different alternatives have been made by the designers to be able to choose a solution that meets the requirements (including the sustainability requirements). It can help to save costs and improve accuracy, but also to make a profit (after the tender phase)	"Because we also have to make a design, we and the architect have made different alternatives for the appearance and the sustainability requirements"	<ul> <li><u>Application</u>: Applied</li> <li><u>Conditions</u>:         <ul> <li>(I) alternatives are developed</li> <li>(II) requirements and other variables are used as criteria</li> <li>(III) skills available</li> </ul> </li> </ul>

		3. REQUIREMENTS		
3.1. Link SE database with model	The link with the SE database contributes indirectly to a more accurate tender price, because the database specifies the conditions or specifications the product has to meet. As a result, a better solution and model can be developed, and can be (automatically) verified based on the requirements in the database. In addition, the database provides insight into the requirements and specifications, and the information is in one place and linked to each- other.	In this project, a SE pilot has been conducted, and attention has been paid to the specification of the requirements: The requirements have been put into Relatics to create an overview. After the tender phase, the requirements will be transformed in measurable requirements and converted into verification plans. The functions are described as rooms. The database is not linked to the model. There are no ICT resources for this. However, the requirements are linked to objects and functions	"In this project, we have used Systems Engineering as a pilot we intend to put the requirements in Relatics, make them SMART and convert them into a verification plan" "Until now we only structured the requirements in Relatics. The rest (SMART requirements and the verification plan) will be carried out later (after awarding). " "Working with Relatics helps to create an overview and create insight so that we know how to meet customer expectations this helps to clarify the unclear demand specification (PoR)"	<ul> <li><u>Application</u>: SE database available, but not linked with the model</li> <li><u>Conditions</u>: (I) functions described (II) objects described (III) requirements in the database, but these are not measurable (IV) no info in database. System and environment have been analysed though (V) ICT resources for the database available but the database is not linked to the model (VII) this is a pilot, so DVBH is busy to acquire the skills</li> <li><u>Pre-activities</u>:</li> </ul>
				4.2
4.1. Link model with price database	Linking the model with a price database results in an accurate tender price, by using actual price information (Liu & Zhu, 2007).	4. INFORMATION For this project, no model-linked price database has been used because there is no model available and DVBH used price information without the use of a database	"We have not used BIM yet" "We use Kental, but no model is required for this"	<ul> <li><u>Application</u>: Not applied</li> <li><u>Conditions</u>: (I) no ICT resources available (II) no database that is kept up-to-date (III) no database, but</li> </ul>
4.2. System and environmental analysis	The system and environmental analysis results in an accurate tender price by reducing unforeseen costs by gaining insight into the scope, system, environment and condition of the soil.	A stakeholder analysis and an analysis of the construction site and the environment have been conducted. This helps to create insight in the project and to match the work with the constraints of	"The customer and market department makes a stakeholder analysis and looks at the most important stakeholders. A diagram shows whether stakeholders can directly or indirectly influence the	Application:     Applied     Conditions:     (I) skills available

		the building site.	project"		
			the construction site we have		
			our design on that analysis so that		
			we will not be surprised later"		
4.3. Link model with	Linking the model with a policy and regulation	Respondents are not very familiar	"We have not used BIM yet"	•	Application:
database policies and	database results in an accurate tender price by	with this technique, and no	"I do not know that"		Not applied
regulations	reducing unforeseen costs caused by policies and	suitable ICT resources are	"We using a building decree test,	•	Conditions:
	regulations (Valdes, 2016).	available. A building decree test	for example for testing daylight		(I) no ICT resources
		has been carried out to test	requirements in the building		available
		policies and regulations.	decree"		(II) no database that is
					kept up-to-date

		Landelijk Opslag Archief (LOA)		
Activity	Expected pattern	Observed pattern	Examples	Similarities and differences
		1. MODEL		
<u>1.1. Calculation based</u> <u>on the model</u>	Calculating the cost based on an integral 3D model results in a more accurate tender price. This is because a model is more accurate than 2D drawings (Ghaffarianhoseini, et al., 2016). It also saves the calculator time because they no longer need to quantify by hand, because it is done automatically (Autodesk, 2007).	In the tender phase there is no model available and the calculation has been conducted based on drawings (2D information). After the tender phase, a model has been made, but it was not at the right (LOD) level to use it for calculation.	"The calculation was made based on 2D information, not the model" "We can not always use the model because the quantities we get from the model (which is often m2 / m3) are not enough to make a good price the model is often not at the right (LOD) level"	<ul> <li><u>Application:</u> Not applied</li> <li><u>Conditions</u>:         <ul> <li>(I) no LOD300/350</li> <li>(II) no 4D info</li> <li>(III) no verification of the model</li> <li>(IV) no integral modelling during tender phase, only after tender phase</li> <li>(V) no link with a price database</li> <li>(VI) ICT resources not available</li> <li>(VII) skills not available, calculation is done by hand</li> </ul> </li> <li><u>Pre-activities:</u> 1.2/1.3/1.4/1.5/4.1</li> </ul>
1.2. V&V of the model	The verification and validation of the model and	In the tender phase there is no	"We wanted to use the Briefbuilder	<u>Application:</u>
	its documentation results in a more accurate	model available, so no V&V based	plug-in, but this proved not to be	Verification and
	tender price by checking if the model meets the	on the model has been carried out.	very useful"	validation by verifying 2D
	requirements. This improves the quality of the	The verification is performed by	"We have checked the drawings by	drawings based on

	documentation and the tender price is based on more accurate information (Woodcock & Forder, 2012; Honour, 2004).	verifying drawings by means of verification plans/requirements. After the tender phase, DVBH tried to use an automatic plug-in, but this plug-in proved not to be useful.	means of verification plans so we know that our drawings meets the requirements"	<ul> <li>verification plans.</li> <li><u>Conditions</u>:         <ul> <li>(I) SE database available</li> <li>(II) no LOD300/350</li> <li>(III) ICT resources not available</li> <li>(IV) no skills for verification based on model</li> </ul> </li> <li><u>Pre-activities</u>:         <ul> <li>1.4/3.1</li> </ul> </li> </ul>
1.3. Conflict control	The conflict control results in a more accurate tender price by filtering errors in the model and models of other disciplines (Ghaffarianhoseini, et al., 2016). As a result, the cost price is based on more accurate information. With a conflict control, cost savings of 10% of the contract value can be achieved (Ghaffarianhoseini, et al., 2016).	In the tender phase there is no model developed and no conflict control has been performed. After the tender phase, the conflict control has been conducted to check the work of various disciplines and to gain insight into the work of others and conflicts between information	"A conflict control (after the tender phase) was needed to check the work of other parties" "After the tender phase, a clash control has been performed to verify that the work is in line with our model" "It reduces failure costs, I think, and gives insight into the work of others"	<ul> <li><u>Application</u>: Not in the tender phase, but after the tender phase.</li> <li><u>Conditions</u>: (I) no LOD350 in tender phase (II) ICT resources available (III) skills available</li> <li><u>Pre-activities</u>: 1.4</li> </ul>
<u>1.4. Integral 3D</u> modelling	Integral 3D modelling results in a more accurate tender price, because the quality of the documentation is increased and the price is based on more accurate information. A 3D-model is more accurate than 2D drawings (Ghaffarianhoseini, et al., 2016). In addition, insight is gained into the complexity of the project using visualizations (Ghaffarianhoseini, et al., 2016). Changes can also be quickly implemented in the integral model, saving 7% of the total project time (Ghaffarianhoseini, et al., 2016).	Integral modeling has only been performed after the tender phase. In the tender phase there is not enough time for this activity. After the tender phase, the activity has been used to make drawings for the building application and production drawings. It helps to get insight into the building. According to the respondents, the failure cost can be reduced when using this activity.	"We used BIM to create work drawings and production drawings" "We used BIM to match the work of our partners and to gain insight into each other's work" "We only applied BIM after the tender phase. For this we have used other activities like Sketch- up" "BIM helps to reduce failure costs, because you first think and model before you build"	<ul> <li><u>Application</u>: Not applied in the tender phase</li> <li><u>Conditions</u>: (I) suitable solution available (II) no LOD300/350 in tender phase, only after tender phase (III) prioritization based on risks and phase (IV) integral cooperation in the model only after tender phase (V) ICT resources available (VI) skills available</li> </ul>

				Pre-activities:
				2.1/3.1/4.3
<u>1.5. Building flow</u> <u>simulation (4D BIM)</u>	Building flow simulation (4D BIM) results in an accurate tender price by gaining insight into the constraints of the construction site (Chau, Anson, & Zhang, 2004), reducing unforeseen costs. Also construction and labour costs can be calculated based on the model. This model is more accurate than 2D drawings (Ghaffarianhoseini, et al., 2016).	The project is delayed due to the finding of asbestos. Because of this the project is still in the preliminary design phase. In this phase, no building-stream simulation has been carried out.	"we did not use this activity"	<ul> <li>Application: Not applied</li> <li><u>Conditions</u>:         <ul> <li>(I) no model with 4D info</li> <li>(II) information about restrictions of the construction site available</li> <li>(III) requirements about site and planning available and translated</li> <li>(IV) ICT resources available</li> <li>(V) skills available</li> </ul> </li> <li>Pre-activities: 1.4/3.1/4.2</li> </ul>
<u>1.6. BIM tools for soil</u> analysis	Using BIM tools for soil analysis results in a more accurate tender price by using (existing) soil models, which allows the design to fit the soil condition (Kessler, et al., 2015). This gives insight into the condition of the soil and can therefore reduce unforeseen costs.	The respondents are not very familiar with this technique and is therefore not applied. Also, it is not applied because ICT resources and skills are absent.	"We did not use this" "I do not know this" "We visited the building site and performed a variety of experiments we have looked for asbestos"	<ul> <li><u>Application</u>: Not applied</li> <li><u>Conditions</u>: (I) no model of the soil available (II) no integral 3D-model available (III) no conflict control (IV) no ICT resources available (V) no skills available</li> <li><u>Pre-activities</u>: 1.3/1.4</li> </ul>
		2. SOLUTION		
2.1. Trade study	The trade study contributes (indirectly) to a more accurate tender price by choosing an appropriate solution that meets the requirements and other criteria (Office of Engineering and Construction Management, 2003).	Various alternatives have been developed to select the best solution that meets the requirements, for example, daylight and energy requirements. It can help to save costs, improve accuracy, and to make a profit (after the tender phase)	"We have developed several alternatives using Sketch-up to choose the best option, for example, daylight, energy"	<ul> <li><u>Application</u>: Applied</li> <li><u>Conditions</u>: (I) alternatives are developed (II) requirements and other variables are used as criteria</li> </ul>

				(III) skills available
		3. REQUIREMENTS		
3.1. Link SE database with model	The link with the SE database contributes indirectly to a more accurate tender price, because the database specifies the conditions or specifications the product has to meet. As a result, a better solution and model can be developed, and can be (automatically) verified based on the requirements in the database. In addition, the database provides insight into the requirements and specifications, and the information is in one place and linked to each- other.	3. REQUIREMENTS The client has provided a Briefbuilder file with a large number of requirements, which stimulated DVBH to use Briefbuilder too. The requirements have been analyzed, are converted into SMART requirements and verification plans (during the tender phase). Because this process is new to DVBH, the benefits of this process are not clear yet. The application of Briefbuilder made it difficult to find requirements and there was no overview of requirements and the information in the database. Also, it takes a lot of time to translate requirements into measurable specifications. DVBH attempted to link the database with the model using a plug-in, but this did not work well.	"The client delivered many requirements in a Briefbuilder file. As a result, we decided to apply Briefbuilder and Systems Engineering " "We had little knowledge of the UAC-IC and Systems Engineering, so this process went awry but was necessary to inquire and sort out all the requirements" "We translated the requirements (SMART), converted them into a verification plan and stored this in Briefbuilder. Also, the interfaces have been put in Briefbuilder" "We have to translate the requirements, because sometimes there were vague, this was very difficult" "Briefbuilder was not the best tool. It was hard to find things" "We have lost a lot of time in analyzing all the requirements (hecause of Briefbuilder)"	<ul> <li><u>Application</u>: SE database available, but not linked with the model</li> <li><u>Conditions</u>: (I) functions described (II) objects described (III) requirements in the database, and converted into measurable requirements (IV) no info in database. System and environment have been analysed though (V) ICT resources for the database available but the database is not linked to the model (VII) this is a pilot, so DVBH is busy to acquire the skills</li> <li><u>Pre-activities</u>: 4.2</li> </ul>
				4.2
4.1. Link model with price database	Linking the model with a price database results in an accurate tender price, by using actual price information (Liu & Zhu, 2007).	4. INFORMATION For this project a model-linked price database has not been used.	"We did not use Kental because there is not enough data available in Kental for renovations of existing buildings" "I only know Kental, but it's not used in this project"	<ul> <li><u>Application</u>: Not applied</li> <li><u>Conditions</u>: (I) no ICT resources available (II) no database that is kept up-to-date (III) no database, but prices available</li> </ul>
4.2. System and environmental analysis	The system and environmental analysis results in an accurate tender price by reducing unforeseen costs by gaining insight into the scope, system, environment and condition of the soil.	A big part of the analysis was already performed by the client. DVBH had to investigate the location, but the respondents	"A big part had already been done by the client, but we had to examine the location ourselves" "We did not investigate the	<u>Application</u> :     Applied <u>Conditions</u> :     (I) skills available

		indicate that this was not done well. Later in the process a lot of asbestos has been found. This resulted in cost, delay and changes in the design	location sufficiently because we did not know exactly what our responsibilities were." "We found asbestos in the façade later on" "Because there is an existing building, we have both visited the site and analyzed old drawings of the property"	
<u>4.3. Link model with</u> <u>database policies and</u> <u>regulations</u>	Linking the model with a policy and regulation database results in an accurate tender price by reducing unforeseen costs caused by policies and regulations (Valdes, 2016).	Respondents are not very familiar with this technique, and no suitable ICT resources are available. A building decree test has been carried out to test policies and regulations.	"I do not know this" "We are reviewing the policies, for example, the building decree"	<ul> <li><u>Application</u>: Not applied</li> <li><u>Conditions</u>: (I) no ICT resources available (II) no database that is kept up-to-date</li> </ul>

Activity	Impact/improvements	Differences **	Impact score	Effort score
		1. MODEL		
<u>1.1. Calculation based</u> on the model	<ul> <li>Improving accuracy with a bias as low as +/-3% (Ghaffarianhoseini, et al., 2016)</li> <li>Time saving by reducing calculation time (Autodesk, 2007)</li> </ul>	<ul> <li><u>Conditions</u>: (I) no LOD300/350, (II) no 4D info linked to the model, (III) no verification of the model, (IV) no integral 3D modelling in the tender phase, but after the tender phase, (V) no link with price database, (VI) ICT resources for exporting quantities available, but not for automatic calculation, (VII) skills not always available, calculation carried out by hand.</li> <li><u>Pre-activities</u>: 1.2/1.3/1.4/1.5/4.1</li> </ul>	<b>High</b> : this activity has a high impact, because this activity improves accuracy immediately and also results in a reduction of calculation time	Difficult: this activity requires a lot of effort because of the need to invest in ICT resources and skills. Other activities are also needed, such as the V&V (activity 1.2), modelling (activity 1.4) and the link of the model with the price database (activity 4.1)
<u>1.2. V&amp;V of the model</u>	<ul> <li>Verified model that meets the requirements (Woodcock &amp; Forder, 2012; Honour, 2004)</li> <li>Activity for quality assurance (UAC-IC)</li> </ul>	<ul> <li><u>Conditions</u>: (I) SE database (Relatics) available, (II) no LOD300/350,, (III) no suitable ICT resources, (IV) no skills available for verification based on the model, but skills available for validation based on the model (after the tender phase)</li> <li><u>Pre- activities</u>: 1.4/3.1</li> </ul>	<b>High</b> : this activity has a high impact because verification is important for an UAC-IC project to demonstrate the quality and to prove that the requirements are met. This improves the accuracy of the model and therefore also the accuracy of the price. In addition, this activity provides a time-saving	<b>Difficult</b> : this activity requires much effort because of the need for ICT resources and skills and other activities, such as modelling (activity 1.4) and the SE database (activity 3.1)
1.3. Conflict control	<ul> <li>Improved accuracy by means of a reduction of costs (10% of the contract value) (Ghaffarianhoseini, et al., 2016)</li> <li>Improved model quality, because the model is more consistent (Azhar, Nadeem, Mok, &amp; Leung, 2008)</li> </ul>	<ul> <li><u>Conditions</u>: (I) no LOD350 in tender phase, only after tender phase, (II) ICT resources available, (III) skills available</li> <li><u>Pre- activities</u>: 1.4</li> </ul>	Average: This activity has an average impact because it can save costs by removing errors from the model, but it is not a prerequisite for other activities	<b>Easy</b> : ICT resources and skills are already available for this activity. However, the 3D-model must be available too.

# Appendix 3. Impact and Effort per activity

<u>1.4. Integral 3D</u> <u>modelling</u>	<ul> <li>Improved accuracy, because a 3D-model is more accurate compared to 2D drawings (Ghaffarianhoseini, et al., 2016)</li> <li>Gaining insight into the model/product (Ghaffarianhoseini, et al., 2016)</li> <li>Quickly implement changes (Ghaffarianhoseini, et al., 2016)</li> <li>Time savings of 7% of the total project duration (Ghaffarianhoseini, et al., 2016)</li> </ul>	<ul> <li><u>Conditions</u>: (I) suitable solution available, (II) no LOD300/350 in tender phase, only after tender phase, (III) prioritization based on risks, importance (in one case also phase), but not on other criteria, (IV) integral cooperation in one model only after tender phase, (V) ICT resources available, (VI) skills available</li> <li><u>Pre- activities</u>: 2.1/3.1/4.3</li> </ul>	<b>High</b> : 3D modelling is a prerequisite for many other activities, such as calculation, verification, conflict control and the building flow simulation. It also helps to improve accuracy, because a model is more accurate than 2D drawings, which also makes the price more accurate.	Average: ICT resources and skills are already available, but time must be invested to be able to develop a model in the tender phase.		
<u>1.5. Building flow</u> <u>simulation (4D BIM)</u>	<ul> <li>Improved accuracy by reducing unforeseen costs and the calculation of labour and equipment costs based on the model (Ghaffarianhoseini, et al., 2016; Chau, Anson, &amp; Zhang, 2004)</li> <li>Gaining insight into the restrictions of the construction site (Chau, Anson, &amp; Zhang, 2004)</li> </ul>	<ul> <li><u>Conditions</u>: (I) no model with 4D info, (II) information about restriction construction site available, (III) requirements about construction site/planning available (IV) ICT resources available, (V) skills available</li> <li><u>Pre- activities</u>: 1.4/3.1/4.2</li> </ul>	Average: This activity reduces unforeseen costs from building site constraints and also helps to calculate costs for the construction site and work	Average: For this activity suitable ICT resources and skills are available, but a 3D-model is also required (activity 1.4). In addition, the requirements must be clear and measurable (activity 3.1).		
<u>1.6. BIM tools for soil</u> <u>analysis</u>	<ul> <li>Improved accuracy by reducing unforeseen costs</li> <li>Gaining insight in the condition of the soil (Kessler, et al., 2015). This activity helps to meet the requirement of the UAC-IC contract (art. §13 UAC-IC 2005).</li> </ul>	<ul> <li><u>Conditions</u>: (I) no soil model available, (II) no 3D model available, (III) no conflict controle conducted, (IV) no ICT available, (V) no skills available</li> <li><u>Pre- activities</u>: 1.3/1.4</li> </ul>	Low: This activity reduces unforeseen costs caused by the soil condition. Respondents, however, think that the soil drilling test and construction site analysis provide enough insight into the soil condition	<b>Difficult</b> : This activity requires an investment in ICT resources and skills and a 3D-model must be available (Activity 1.4). In addition, a model of the soil must also be available		
3. REQUIREMENTS						
3.1. Link SE database with model	<ul> <li>Improving accuracy by specifying the performance of the most suitable solution (Dori, 2016)</li> <li>Gaining insight in the requirements and specifications</li> <li>Structured information, all in one place</li> <li>Input for automatic verification</li> </ul>	<ul> <li><u>Conditions</u>: (I) in 2/4 cases functions specified, (II) in 2/4 cases objects specified, (III) in 2/4 cases requirements stored in database. In 1/4 cases requirements converted into measurable requirements and verification plans. Prioritization based on risk and phase, (IV) for all case no information in the database, but information about system and environment</li> </ul>	High: This activity has a high impact, as it is a prerequisite for many other activities and it helps to understand the requirements. This is very important for a UAC-IC project to prove	Average: This activity requires an investment in skills. DVBH has already invested in a pilot project, but the skills need to be expanded. ICT resources for the SE database are		
	(Valdes, 2016; Baker, et al., 2000;	has been collected (V) ICT resources for the	whether the	available, but resources		

	Polit-Casillas & Howe, 2013)	<ul> <li>database available, but the database is not linked with the model, (VII) skills not or limitedly available</li> <li><u>Pre- activities</u>: 4.2.</li> </ul>	requirements are met. for linking the database with the model are not available.			
4. INFORMATION						
4.1. Link model with price database	<ul> <li>Improving accuracy by using actual price information (Liu &amp; Zhu, 2007)</li> </ul>	<ul> <li><u>Conditions</u>: (I) no ICT resources available, (II) no database available, so no one keeps it up- to-date, (III) price information is available but not stored in a database</li> </ul>	Low: This activityAverage: This activityimproves accuracyrequires an investmentdirectly by working within ICT resources and acurrent prices. But,responsible person thatDVBH already worksmaintains the database.with actual prices,without a model-linkeddatabase			
4.3. Link model with database policies and regulations	<ul> <li>Improving accuracy by reducing unforeseen costs (Valdes, 2016)</li> </ul>	<ul> <li><u>Conditions</u>: (I) no ICT resources available, (II) no database available, so no one keeps it up- to-date</li> </ul>	Low: This activity helpsAverage: This activityto take into account the requirements from therequires an investmentbuilding decree. DVBH does this without an actual link with the model (separate building decree test)responsible person that			