Design Change in BIM

Design change management with the use of BIM in the execution phase of infrastructural projects

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In partial fulfilment of the requirements for the degree of Master of Science in Construction Management and Engineering at Delft University of Technology

Thesis defended publicly on 07 October 2019 at 11 AM

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''As far as BIM is concerned, design change management seems to be one of the biggest advantages."

(Juszczyk, Tomana, & Bartoszek, 2016, p. 521)

Acknowledgements

The past year, I worked on this research by reading papers, interviewing experts, performing a data-analysis and developing a procedure which all evolved in this thesis. That was a lot of work, and I could not have achieved it without the help of my committee.

Therefore, I would like to thank my first supervisor, Alexander Koutamanis, for the feedback provided, and for placing the research into a context with his broad knowledge about BIM. Additionally, thanks to my second supervisor Rob Stikkelman, for all the questions and feedback I was provided with, which improved my decision-making and comprehension of my goal. I want to thank my professor, Hans Bakker, for his feedback which allowed me to achieve a higher academical level and well-structured report.

Furthermore, I want to thank my company supervisors for their guidance during my graduation internship. Brigt Rykkje, for supporting me on a daily basis at BAM Infra and for providing input during my research. Dirk van der Ploeg, thanks for opening your network for me. Moreover, many thanks to all interviewees for their interest in my research and all BAM colleagues who took their time to have a chat about my graduation topic.

Last but not least, I want to thank my dearest family and friends; your support has been precious to me. Also, many thanks to my fellow graduate students who helped me out when I was struggling. In addition, I want to thank Dave for reviewing my English.

All your help made working on this research much more manageable.

Enjoy reading my thesis!

Öznur Bozmaz
Delft, september 2019

Executive Summary

Introduction

Due to the dynamic character of infrastructure projects, change is inevitable. By acknowledging and efficiently managing design change, project success can be maximised. Different design changes can occur during the execution phase of projects, caused by for example incomplete information, clients change request and contractors change request. Many infrastructure projects cope with a cost overrun and time delay due to the lack of effective design change management in case of design changes. To implement these design changes, an effective change process is necessary. This process guides the project team in identifying, documenting, evaluating and managing design change. With this technical tools are needed for implementation of change, namely BIM(Building Information Modelling). By using BIM, assessment is made on whether design changes are feasible and what consequences it may have on planning, costs, re-work, and clashes. However, current knowledge is lacking on how to use BIM when implementing a design change in a project. This research aims to set up a procedure that can be used by the project team for implementing design changes during the execution phase of infrastructural projects. To achieve this objective, the following research question is answered:

How can design changes be implemented during the execution phase of infrastructural projects, with the use of BIM?

Research method

To answer the main question, case studies are analysed. Hereby, both qualitative and quantitative analyses are carried out in three cases in the infrastructural field. Both analyses are subdivided into the organisational dimension(for the change process) and technical dimension(use of BIM). For the qualitative part, semi-structured interviews are held with contract managers and BIM managers. For the quantitative part, samples are taken to analyse each project. These samples consisted of all contractual changes in the project that led to a change in the design and which have been implemented after the execution phase has commenced.

Results

In the case studies, it is identified that there is an incomplete change process. Due to impact analyses seldom being performed, the project team and the client are not aware of possible negative consequences for design, construction, risk, time and budget. The unawareness of client and project team of possible consequences clarifies the large number of changes within all analysed projects. The number of changes is expected to be much lower if the project team or client is aware of all consequences. Currently, BIM is at level 1(visualisation) and partly at level 2(documentation) of BIM usage. It is identified that members of the project team that do not work with BIM see the value of BIM mainly in clash detections. BIM managers and modellers mention the integration of data and information processing. In each project, the design changes cost between the 3.8-4% of the total project and these are the direct costs. Indirect costs as loss of efficiency due to process disturbance and loss of effort on work already done are not measured.

In order to reach a higher efficiency during the implementation of design changes in the execution phase of infrastructural projects, a procedure is set up. By using this procedure, the project team gains a full understanding of how the design change process should proceed and which steps they have to take for effective implementation of design change with using BIM. Also, by following this procedure, it is aimed to minimise the number of changes, by performing impact analyses and asking for project team approval before proceeding to implementation.

Together with the procedure, the structure of the project information is also illustrated with a scheme. Hereby, all steps that have an input or output for one or more databases are shown together with the type of information that is gathered or registered in the database.

Discussion and recommendations

A procedure is set up and will be introduced in the company. First, the use of BIM3D should be optimised to reach level 2(documentation). Using this procedure means that a level of 3 and 4 of BIM usage are reached. For this, a culture change has to be realised. This is possible by the support of the management team, as they determine the objectives for the organisation and control the financial resources.

First, the ICT department needs to design the links between the databases: Relatics, BIM models and DMS(Document Management System), so there is no parallel information flow present, and all these databases can be referred to as BIM. Simultaneously, a culture change must be promoted. As each employee has to follow courses each year, the next session should be a BIM-related course, with emphasis on the information side of BIM. Hereafter, BIM courses with a focus on modelling should be possible to follow for the whole organisation. However, these should be mandatory for design and work preparation team.

It is recommended to implement this procedure only in new projects, as it can be difficult in an ongoing project. At the start of each project, the project team has to follow a course based on this procedure, and each year, this has to be repeated. The process manager maintains the procedure, and each year, it should be reviewed whether the procedure is still up-to-date considering new developments. In the case of automation, most steps in this procedure will take less time. The more the BIM process is automated, the more advantages BIM delivers for design change management and the more level 5 is reached of BIM usage.

Further research can focus on how this procedure works in practice, the adoption of this procedure in the infrastructure field and automation of this procedure.

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List of abbreviations

BIM	Building Information Modelling
DB	Design & Build
DBFM	Design Build Finance Maintain
IFC	Industry Foundation Classes
LOD	Level of Development
UAV-gc	Uniforme Administratieve Voorwaarden geintegreerde contracten

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01

Introduction

Project success can be maximised by the recognition of the dynamic character of construction projects(Dvir & Lechler, 2004). Thus, the project team should realise that changes to the project are inevitable due to the dynamic character of construction projects.

In the case of a change, it is essential to ''Incorporate a balanced change culture of recognition, planning, and evaluation of project changes in an organisation to effectively manage project changes. These changes include: Scope, error, design development, estimate adjustments, schedule adjustment, changed condition, elective, or required.'' (CII, 2011, pp. 8.9-1)

Therefore, recognising, evaluating and planning the change is essential to manage it effectively. Several changes, as mentioned, can occur during the project. An error, design development, and estimate adjustments are design changes that can lead to schedule adjustments. Design changes may lead to scope changes when they do not meet the requirements of the contract. A design error or a changed condition is a necessary change, and a scope change or a schedule adjustment on its own may be elective.

In construction projects, decisions often have to be made with incomplete information: based on assumptions and personal experience. If these assumptions, in a later stage, are proven to be incorrect, changes have to be made to the project(Sun, Fleming, Senaratne, Motawa, & Yeoh, 2006). Other common reasons for change are design errors and omissions(Keane, Sertyesilisik, & Ross, 2010). These errors involve poor design and inadequate construction details. Furthermore, change requests by the client and change of technology are mentioned in literature(Nahod, 2012). All these causes, namely: Incomplete information, design errors, change requests by the client and change of technology, lead in many cases to design changes, which eventually may lead to rework during the execution phase.

An effective design change management model is required to implement these design changes. Literature mentions different types of these models and most of them have a similar approach. Following each stage helps the project team in identifying, documenting, evaluating and managing design change. Within a design change management model, technical tools are necessary to implement change. Nowadays, this is offered through BIM(Paik, Leviakangas, Morrison, Naas, & Wang, n.d.).

1.1 Problem description

Many infrastructure projects are confronted with a cost overrun and time delay(Flyvbjerg, Garbuio, & Lovallo, 2009). One of the leading causes is the inability to perform effective design change management in the project teams(Sun et al., 2006) in the case of design changes(Auditor General of Western Australia, 2012; Stasis, Whyte, & Dentten, 2013).

When a design change is implemented, it may have an adverse effect on the project drivers, such as time, cost and quality(Hwang & Low, 2012). Using BIM is essential for design change management so that assessment can be made on whether design changes are feasible and to determine what consequences it can have on, e.g. the planning, costs, re-work and clashes(Juszczyk et al., 2016; Mejlaender-Larsen, 2015). Furthermore, each design change that is implemented in BIM is immediately shown in each view and database, which makes it easier for the project team to manage this design change(Autodesk Inc., 2002; Juszczyk et al., 2016).

Currently, knowledge is lacking on how to use BIM when implementing a design change in a project. Earlier research focused on how design change history can be tracked (Liu, Jallow, Anumba, & Wu, 2014) and displayed(Juszczyk et al., 2016) by using IFC(Industry Foundation Class) format. IFC is a standard that enables users of different BIM software to interoperate by exchanging data in the same file format(Eastman, Teicholz, Sacks, & Liston, 2011).

Furthermore, how design changes can be assessed is mentioned in literature (Mejlaender-Larsen, 2015). Pilehchianlangroodi(2012) developed an ontology of different types of design changes in BIM and suggested to do more research to design changes in various types of projects based on this proposed ontology. Moreover, Paik et al. (n.d.) have studied a case on how pro-active design change management was implemented with the use of BIM tools. The sequence of design change management has been made transparent. Following the authors, more case studies should be analysed in order to gain a more reliable outcome of how BIM is used in design change management.

Scientific Relevance of this research

As BIM is advantageous to use in design change management, and as BIM still is not fully adopted by the infrastructure field, it is valuable to find out to what extent BIM is used now in these projects. Hereby, the user-friendliness of BIM per infrastructure (design) discipline and the usability of BIM when implementing changes in the design should be highlighted. So that a procedure can be developed that shows how BIM can effectively be used in design change management in this field.

Practical Relevance of this research

At the moment, BIM is not fully implemented within BAM and also not in the change processes. BAM is working on achieving a higher level of BIM implementation in their projects. For this, BIM also has to be incorporated in their processes: for this reviewing is needed of the change processes. Furthermore, available processes are stand-alone and not linked to each other. This means that there is not a complete change process, from ‘’handing in the change request’’ till ‘’approved and constructed on-site’’. Project teams are thus mainly aware of processes they have to proceed, and not of the full context, while that is also important for the information processing.

1.2 Research objective

The objective is to develop a procedure to be used by the project team for the use of BIM during the implementation of design changes during the execution phase of infrastructural projects.

1.3 Research question

How can design changes be implemented during the execution phase of infrastructural projects, with the use of BIM?

1. What is design change (during the execution phase of infrastructure)?
2. What is BIM, and how is it used in the infrastructure industry?
3. How is a design change currently implemented?
4. What is the current user-experience of the project team with BIM?
5. How can a design change be implemented with the use of BIM?
6. How should the project information be structured for the use of BIM-based design change management?

1.4 Scope of research

The scope of this research focuses on the implementation of design changes with the use of BIM during the execution phase of infrastructural projects. These infrastructural projects are based on a Design & Build contract. Contractual changes that lead to design changes are taken into account during this research.

The focus of this research is on how to implement design changes with the use of BIM. The information needed in order to change the constraints in BIM 3D, 4D or 5D is also highlighted in the given procedure. Furthermore, process improvements are suggested for the design of BIM3D. Though, these improvements are not technical as it is not part of the scope.

1.5 Research Design and Thesis Outline

In order to answer the research questions formulated in this chapter, the research design, as shown in Figure 1 is developed. For this research, firstly a literature study is conducted to create a theoretical framework about design change and BIM. The first and second sub-questions are answered in chapter 2. Simultaneously, observations are held in order to gain insight into the process of implementing a design change and the use of BIM in this process. In chapter 3, the research method is described and chapter 4 the case studies are analysed, and results are given. In chapter 4, the third and fourth sub-questions are answered. In chapter 5, a procedure is given based on the results of the literature study and case studies. Hereby, the fifth and sixth sub-questions are answered. Hereafter, in chapter 6, a discussion is provided to analyse the outcome of this research. In chapter 7, an answer to the main research question is provided.

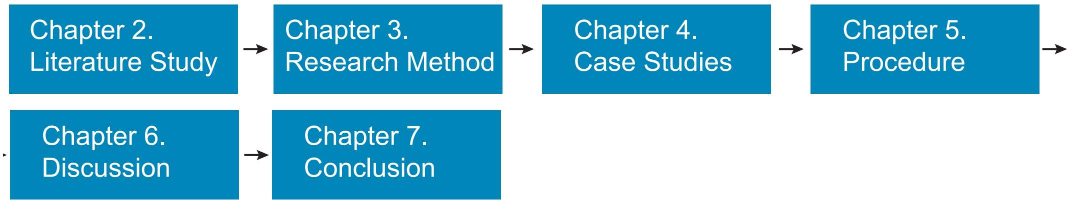

Figure 1. Thesis Outline

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Literature Study

This chapter presents the literature study in order to answer the first two sub-questions:

1. What is design change (during the execution phase of infrastructure)?
2. What is BIM, and how is it used in the infrastructure industry?

In chapter 2.1, the first sub-question is answered by giving an overview of types of design changes during the execution phase, causes and effects of design change and a design change process. Consequently, in chapter 2.2, the second sub-question is answered by describing BIM and its benefits. Furthermore, the link between design change and BIM from literature is given. In chapter 2.3, a conclusion is provided of the created theoretical framework.

2.1 Design Change

This chapter gives an overview of the types of design change; typical causes and effects, and how design change can be implemented in a project.

2.1.1 Types of design change during the execution phase

Within a D&B contract, the design process is linked with the construction process and is running in parallel at a particular moment. Each partial design is then released, as soon as it is ready for construction. The occurrence of design change is most frequent during the final stages of design, and the middle stage of execution, see Figure 2(Koch, Gransberg, & Molenaar, 2001).

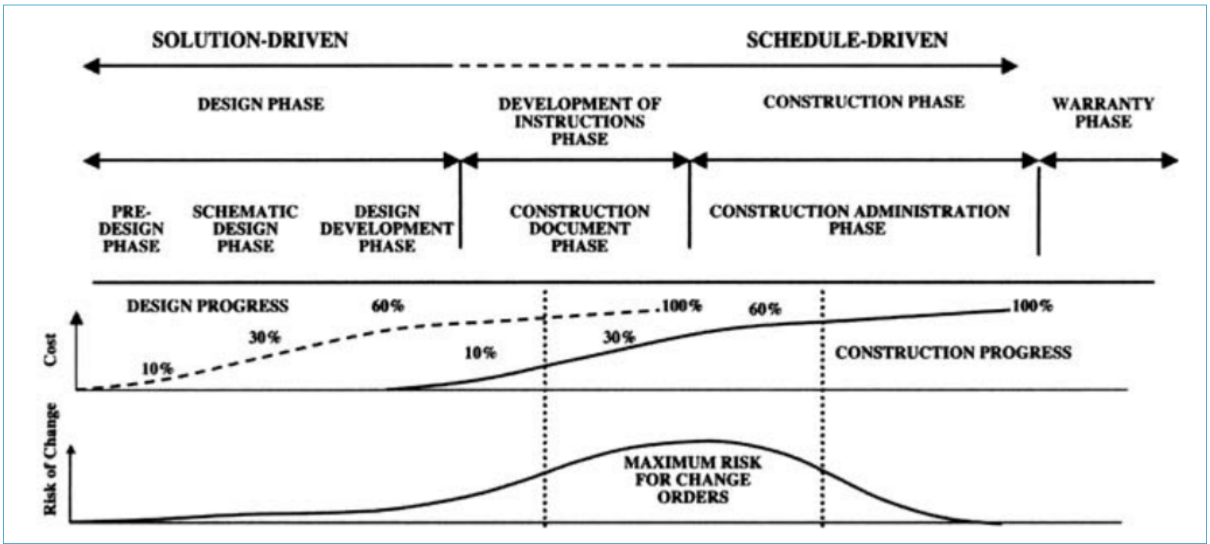


Figure 2. Timeline and impact of the risk of change orders (Koch et al., 2001, p. 197)

Hereby, two different design changes can occur during execution phase in D&B contracts:

- Design changes, after execution phase has commenced, but before the final design has been completed on that part of work;
- Design changes during execution phase, after the final design has been completed on that part of work(Koch et al., 2001).

‘’Design changes result from a modification within the work and may lead to re-design and revision to the contract documents” and therefore may lead to contractual changes and vice versa. (Shourangiz et al., 2011, p. 80). Contractual changes may include changes to the scope. In some cases, the client demands another design solution, which is also according to the earlier set scope requirements. That means that the scope of the contract remains the same. No new requirements are set, no requirements are changed. Only a different design solution is demanded, which takes extra time and costs to implement. This is then a contractual change, as the clients ask for more work to do, without changing the scope(CROW, 2005).

Design changes can be either elective or required(CII, 2011; Sun et al., 2004). Literature also mentions the type of changes included in Appendix A. In the execution phase, it is expected that most changes are:

I. Required, i.e. there is no other option than to implement the design change (Sun et al., 2004);
II. Emergent changes arise unexpected and are not anticipated on, and these design changes often have substantial consequences(Sun et al., 2004);
III. Reactive changes, i.e. the project team has to take measures to minimise the effects of the change(Motawa, Anumba, Lee, & Peña-Mora, 2007);
IV. Detrimental changes have a negative impact on the project and reduce client value(Ibbs, Wong, & Kwak, 2001).

2.1.2 Causes of design change during the execution phase

During the execution phase, most design change orders come from the client; during the design phase, this applies to design-consultants and contractors(Wu, Hsieh, Cheng, & Lu, 2004).

All main stakeholders have their perception of the reasons for change. According to clients, many of their projects do not meet the time and budget(Sun et al., 2004). Reasons for this, according to clients, are that the construction market is complex and challenging to understand; that designers do not elaborate on the design into detail and that contractors think of making profit by neglecting the quality of the construction(Nahod, 2012). On the other hand, design consultants mention late changes requested by the client(Nahod, 2012; Sun et al., 2004). Also is referred to, i.e. the underestimation by the client of the time needed to change the design. The contracting parties have declared that design documentation offered by the design consultant is often incomplete and that the client requests new changes during execution phase(Nahod, 2012).

Sun & Meng (2009) divide change causes in five different categories: “project-related,” “client-related”, “design-related”, “contractor-related” and “external factors”. In the following section, per category, relevant causes are highlighted, which are mentioned in literature.

Project-related causes: Many infrastructural projects are multidisciplinary and complex. Due to the complexity of the work, many decisions are based on uncertain information. If the assumptions, based on personal experience and incomplete information, in a later stage, are proven to be incorrect, changes have to be made to the project(Sun et al., 2006). Moreover, the more complex the project, the higher the chance that design changes occur which leads to rework(Chan & Kumaraswamy, 1997). Another project related cause is that the project teams and stakeholders involved in each construction project are temporary. A way of good collaboration and communication has to be reached in order to deliver a successful project. Unfortunately, poor communication between parties and within project teams often occurs and causes design changes and re-work in construction works(Sun & Meng, 2009).

Client-related causes: Nahod (2012) stated that the additional needs of the project defined by the client are the most common design change in construction projects. This change often results in a change in the requirements and thus in a scope change. Another possible change that is client-related is delivering erroneous or incomplete information at the start and during the project(Chang, Shih, & Choo, 2011). Some clients may experience delays in the review and approval of documents that are received from the contractor. This means that if they do not agree with the delivered documents, changes will be reported later than initially agreed(Chan & Kumaraswamy, 1997). Other common causes are a shortage of funding and difficulties in site acquisition. As infrastructure projects are often being built over a vast area, many different stakeholders may own the sites that have to be built on. If the client has difficulties in site acquisition and cannot agree with the site-owners on time, this will have consequences for the design and execution work(Sun & Meng, 2009). Activities of design and execution work may have to be shifted, which may lead to a change.

Design related causes: Design changes may arise from design errors. These design errors are not always detected before execution phase has commenced and are often due to poor design, inadequate construction details and changes in the pre-construction phase that are not correctly assessed before implementing(Haydl & Nikiel, 2000). These design errors can also arise due to poor communication of design decisions between the design disciplines. As soon as the designs are brought together to be used for construction, these conflicts in design may be discovered by the project team or the subcontractors. This sort of design errors caused by the project team does not lead to contractual changes(Koch et al., 2001).

Contractor-related causes: Defective workmanship by subcontractors can result in non-corresponding built parts and drawings, and therefore, in design changes and rework(Fisk, in Hameed, Rahman, Faris, & Hasan, 2014). This cause can be prevented by proper site management, supervision, and planning by the main contractor(Sun & Meng, 2009). Defective workmanship is tried to be prevented by the contractor and may be beyond control. However, the next cause is under control of the contractor and often elective: The availability of new construction methods or materials may result in change requests by the contractor to obtain a higher income or for easier operations. This also applies when the contractor encounters technological complexity(Nahod, 2012; Sun & Meng, 2009).

External factors: Often, infrastructure projects are being built over a vast area. That means that there is a relative sizeable neighbouring community. This community may form an opposition against the construction plans, and this can result in changes to the design(Sun & Meng, 2009). These projects also have an extensive schedule with design, work preparation and construction activities. As regulations change over time, the longer the project duration, the higher the chance of having to implement new regulations from the government(Hsieh, Lu, & Wu, 2004). Furthermore, unforeseen ground conditions, climate conditions, and economic factors can play a role as a cause in a design change order(Sun & Meng, 2009).

2.1.3 Effects of design change during the execution phase

A significant part of the design changes within a project occur during execution phase and often cause cost and time overruns(Shourangiz et al., 2011). These are explained in this section.

Cost-related effects: Design changes usually result in rework, which leads to extra costs, direct or indirect(Bower, 2000). Direct costs are paid by the client, in case of client-initiated changes(Sun & Meng, 2009). Hereby, the direct costs are related to the tasks that are immediately affected by the design change, in the design and construction. Thus, e.g. the procurement of new materials, standing time for subcontractors in case of construction work, inflation: which can ensure loss of earnings(Bower, 2000), and the extra hours that employees have to work in order to implement the change(Sun & Meng, 2009). The indirect costs are hard to quantify per project. These involve, for example, loss of efficiency and in the case of rework: loss of effort on the design and construction that is already done(Bower, 2000). Hallock (in Koch et al., 2001) mentions that these indirect costs can also be related to the unchanged work that is affected by the design change.

Time-related effects: Design changes can have substantial consequences in time(Shourangiz et al., 2011). This includes the loss of time due to stopping and restarting the task of unchanged work in order to implement the design change(Bower, 2000). As cost and time are interrelated(Sun & Meng, 2009), e.g. standing time of subcontractors and rework also have a time effect. The planning should be updated, to gain insight and mitigate the time consequences. Beyond cost and time-related effects, also productivity, risk, and other effects can occur(Sun & Meng, 2009). With this loss of productivity, disruption in relations occur(Shourangiz et al., 2011).

Nahod (2012) and Koch et al. (2001) stated that the risk of an impact occurring related to change increases during the project. Hanna, Russell and Vandenberg (1999) quantified the effect of changes in labour efficiency. The results showed that the higher the number of changes, the higher the decrease in efficiency. Also, the later the change occurs during the project, the higher the labour inefficiency.

2.1.4 Process of implementing design change

As the possibility of an impact increases during the project, it is recommended not to request changes during the execution phase and if asked to reject these if they are not required(Nahod, 2012). In case of necessary changes, it is recommended to have a sound design change management system, which can reduce the indirect costs related to design change and the time needed to implement design change. This system should also support error-free information flow, keep the project team up-to-date about the status of the design change, and achieve better control of the as-designed and as-built(Hao, Shen, & Neelamkavil, 2008). As mentioned, two design changes can occur during the execution phase, and both must be implemented by a change process. Different change processes are available in literature, from which a few are highlighted hereafter.

According to Motawa et al.(2007), a change process can be divided into among others: identify and evaluate and approval and implementation.

Identify and evaluate: As soon as a change is identified, by the client or the project team, this design change is assessed, and the type of change, causes, and possible effects are defined. With this possible options have to be taken into account. Analysis of these options is required for decision-making(Motawa et al., 2007). An impact analysis can do this. According to Koch et al. (2001) certain aspects have to be reviewed thoroughly. If re-design and re-construction are required, it is analysed which disciplines and departments are affected and the scope of work that has to be implemented. In case of a design change that concerns a part of the work of which the final design has not been completed: Then, not always re-work is required and is it merely a change of work. This also applies to construction work. After having clear what the design and construction disciplines have to implement, cost and time consequences can be calculated, and a change proposal can be drafted. Nahod (2012) also recommends to analyse impact on resources, scope and risk as these can lead to indirect effects.

Approval and implementation: In case of an internal change, the relevant teams are notified immediately(Motawa et al., 2007). In case it concerns a change of which clients approval is needed, the change proposal is sent to the client after approval of the project team(Hao et al., 2008). If approved, the design change is implemented by the project team: Schedule and budget are updated, the design discipline implements the change, and work-preparation and construction team construct the change(Koch et al., 2001). It is possible to ask up to three times for client approval during this process, regarding impact on project goals, project constraints and indirect effects (Nahod, 2012). This ensures that everything discussed and approved is contractually committed. However, it is not necessary, as most change processes in literature suggest one-time approval and asking approval more times will result in more negotiations which will slow down the change process.

During this change process, it is essential to document all steps and communicate internally and with the client about the progress of the design change. The implementation of design changes requires proper management of information both in documentation and design. Due to the complexity of construction design processes, much information has to be processed and managed. Thus, a good flow of information has to be reached, so that is ensured that all relevant departments are notified, up-to-date, and all activities are performed according to the desired design change. Hereby, BIM can be used to process the amount of information of multiple disciplines that work in series or parallel(Hao et al., 2008; Paik et al., n.d.; Zada, Tizani, & Oti, 2014).

2.2 BIM

In this chapter, a theoretical framework is created about Building Information Modelling: To be clear about what is meant by the term BIM and what BIM can make possible. Furthermore, the link between BIM and design change management is highlighted.

2.2.1 BIM in infrastructure

Building Information Modelling is a process that generates a product: an object-oriented representation of a construction. It is, more precisely, a 3D model including all information regarding the properties and requirements of the construction. As all information regarding the construction can be stored in a BIM database, the use of BIM is of great importance for efficient communication and information management within a project team(Turk, 2016). In the next section, this is further highlighted.

BIM 3D can be extended to among others 4D and 5D. 4D can be used to visualise the schedule of construction processes and gain more insight into the planning of the project(Sigalov & König, 2017). BIM 5D enables the project team to estimate the costs of the project(Czmoch & Pękala, 2014).

Ideally, BIM includes all information regarding the project design, construction and business processes(Smith & Tardif, 2009). Currently, BIM uses described in literature in the infrastructure industry are mainly at the level of visualisation and documentation(Cheng, Lu, & Deng, 2016):

1. **Visualisation:** creating 3D and 4D models for visualisation purposes and design review by appearance. Hereby only geometry is modelled;
2. **Documentation:** creation of 3D models to take out quantities, design drawings, construction documentation and lifecycle information management. Hereby geometry and specifications are implemented in BIM(CIFE, 2015).

Ideally, BIM is also used for:

3. **Model-based analysis:** Structural analyses, sunlight analysis, traffic flow simulation, constructability analysis, Cost estimating(5D)
4. **Integrated analysis:** Design change management, integrated 4D and 5D models and clash detection;
5. **Automation and optimisation**(CIFE, 2015).

According to Cheng et al. (2016), most used possibilities of BIM are design review, clash detection, taking off quantities and constructability analysis. Except for design review, the rest can be made use of during the execution phase, when the final design is already completed.

2.2.2 Benefits of BIM

Design change management during each phase of the project is one of the most significant advantages. By using BIM, the project team can see immediately the effect of the design change made to the project in each view and database(Juszczyk et al., 2016). This helps, in turn, to manage these design changes better, as it is clear which interface the change applies to. Another benefit of BIM is the ability to carry out clash detections. This can significantly reduce design errors before the execution phase commences(Shourangiz et al., 2011).

Furthermore, there is no room for interpretation of objects in the BIM model(Turk, 2016). In 2D, a cylinder (as a symbol) for example could be mistaken for a structural column(as an object), while it could also be another element. In BIM, by contrast, every symbol is assigned to an object within the information database. This ensures clear communication and information sharing.

This complete information sharing in BIM leads to improved communication, coordination and collaboration within the project team. Hereby, the client is able to understand (further) project needs. An analysis of design alternatives can be executed, and the design team can implement further developments of the project. The contractor can use BIM to manage the execution of the construction project. Complex constructions can be modelled in more detail in 3D and construction sequences can be visualised in 4D. All this information sharing will ensure better project control(Grilo & Jardim-Goncalves, 2009). Therefore BIM should not only be considered as a design tool: it is a useful tool for project management(Rokooei, 2015).

2.2.3 Type of design change in BIM

Design change in BIM can be distinguished in:

Table 1 Type of Design change in BIM. Adopted from (Pilehchianlangroodi, 2012, p. 38)

Type of change in BIM	Sub-type:	May lead to:
Change in type of object (3D)	Addition of new component	Change in planning (4D); Change in costs (5D); Combination of mentioned changes.
	Modification of component	
	Deletion of component	
Change in interface between objects (3D)	Analytical: relationship between disciplines	
	Spatial: connected, adjacent, supported or surrounded by (within discipline	
	No interfaces	
Change in component attributes (3D)	Geometry (shape or dimensions)	
	Position (in coordinates or orientation)	
	Specification (Materials or properties)	
Combination of mentioned changes		

2.2.4 Design change Management with the use of BIM

As people enter most information of the construction project in databases, the quality, reliability and the level of development of the available data can differ. Still, this information is valuable, despite that it may be incomplete at times(Smith & Tardif, 2009). Notable with this is that the information in a BIM database should not be part of a parallel information flow: Information regarding the same object or activity should contain precisely the same information in different databases which are all part of BIM. So, when a design change is going to be implemented, no errors occur due to incorrect (coordination of) information.

As different design disciplines use different software, interfaces must be visible in their own 3D model with other disciplines. This can be achieved with the use of Worksets (or Custodianship). This is a database concept that forms a whole group of breakable parts(Turk, 2016). This whole group consists of the whole 3D model, which is divided into more sub-models or breakable parts. Hereby multiple users can work separately and simultaneously within the 3D model. Parts of the model can be locked to be changed by another or hidden in the complete model, depending on the use and owner-rights of the modeller. This way, design changes can be implemented correctly as all interfaces are clear, and the modeller can restrict others to work in that part of the model, so no errors arise.

Design changes can relate to different types of change in BIM, as illustrated in Table 1. The modeller can implement this manually in the object, or make use of already generated object type libraries. The latter saves time and prevents the risk that, e.g. the modeller forgets to change the properties of an object when changing the geometry. An Object Type Library(OTL) is a collection of types of construction objects and their properties. Developing an OTL is costly and takes time; however, once this library is operational, a lot of money and time can be saved on future projects(Bouw Informatie Raad, 2011).

2.3 Conclusion of literature study

During the literature study, a theoretical framework is created for design change management and its link with BIM. It is mentioned that two types of design change can occur during execution phase in D&B contracts, namely design changes from which the design is still in progress on that part of work, and design changes from which the design was already completed on that part of work. Hereby, client-initiated changes often cause changes during the execution phase. Design changes occur mostly in the final stages of the design phase and the middle stage of the construction phase. The later the design change is requested and implemented, the higher the impact on project constraints. Also, the more design changes are implemented, the higher the inefficiency becomes. These changes are implemented following specific change processes. All steps should be documented and communicated with the client and within project team. The amount of information that has to be processed during these design change processes require technical tools as BIM.

BIM is a process which generates a product in 3D, that can be extended to among others 4D(time) and 5D(costs). Currently, in infrastructure, BIM is used mainly for visualisation and documentation purposes. BIM has several benefits for design change management, clear communication and information sharing, which leads to better project control. In case of design changes, these can lead to different types of change in BIM3D, which again may lead to a change in 4D and eventually in 5D. If using BIM correct with live links between all databases, live interfaces and always filling in information: the project team can make the most of named benefits.

In order to make use of design change management in BIM, and reach level 4: integrated analysis, a procedure has to be set up to make clear what the steps are from initiation till approval on site. For this, first case studies are analysed, to comprehend how design change is implemented in infrastructure projects and what the user-experience is with BIM. In the next chapter, it is described how the case studies are set up.

03
Research Method

This chapter gives an overview of the chosen research method, of how the cases are chosen, how the qualitative and quantitative analysis are performed, how the results are reviewed, what the procedure includes and how this is validated.

3.1 Research methodology

Case studies are used as a methodology to find out how design changes are managed with the use of BIM in the infrastructure field. The case studies make use of the observations.

Case studies consist of collecting and analysing data in a qualitative way out of a small number of cases. This means that data is analysed by sorting and comparing the results. Triangulation of sources is used to create depth and to analyse different dimensions in the subject: Data is collected from observations, face-to-face interviews and textual documentation. The aim is to generate a holistic view on the practice of design change management related to BIM by analysing three cases. This is possible by taking a strategic sample out of the collected data(Verschuren & Doorewaard, 2010). The sample selection is explained in chapter 4. In order to gather more in-depth information and see correlations, this strategic sample is also analysed quantitively using a data-tool: PowerBI.

The deliverables of the case studies are as follows:

- Insight into the causes and effects of design changes in infrastructure;
- Insight into how design changes are implemented;
- Insight into the utilisation of the possibilities of BIM;
- Insight into user-experience of the project team with BIM.

3.2 Selection of cases

The case studies are chosen, based on specific criteria, as shown in Table 2. Each case study is analysed briefly to determine whether the case conforms the established criteria. The established criteria originate from the following:

- The case should be an infrastructure project, as this research focuses on that area;
- BIM should have been used in the project so that sub-questions 3 and 4 can be answered;
- The project should now be in the execution phase or recently finished, as the research focuses on the execution phase, and participants then will remember more details if it is current or recently finished;
- Possibility to access project information and to interview participants in order to have access to all required data and to conduct a proper case study analysis.

Five cases were selected initially for observation, from which 3 are kept. Participants of these selected cases have been interviewed during the observations. Two of these projects are not analysed further after observation. As the first one was at that time still in the pre-execution phase, it did not fulfil the criteria of the case studies. The second has a DBFM contract in contrast to the other selected cases. The latter have a D&B contract. From interviews, it appeared that there is an entirely different change process within these contracts. So, in order to have a comparable case, another criterion is added to the case selection:

- Project is based on a UAV-GC 2005 contract.

Table 2 Case criteria.

	Criteria	Case A	Case B	Case C
1	Infrastructure project	✓	✓	✓
2	Use of BIM in the project	✓	✓	✓
3	Execution phase has started or already completed	✓	✓	✓
4	Possibility to access project information	✓	✓	✓
5	Possibility to interview participants	✓	✓	✓
6	UAV-gc contract	✓	✓	✓

3.3 Qualitative analysis

For the qualitative analysis, interviews have been held with contract managers and BIM coordinators who participated in the project. These interviews aimed to map the change process and the process of using BIM by the project team.

These face-to-face interviews consisted of open questions, see Appendix B. These interviews were semi-structured, and depending on the response of the interviewee, additional questions have been asked during the interview(Verschuren & Doorewaard, 2010). Each interview is recorded with approval of the interviewee, and after each interview, findings are summarised and sent to the interviewee for confirmation. The interviews are only used as data when the interviewee has agreed upon the summary of the results.

3.4 Quantitative analysis

Project documentation is used for further investigation of the cases. As information from interviews may be biased or incomplete, it is essential to analyse the project documentation quantitatively. The project documentation that is used consists of:

- All design change proposals and forms;
- The planning of the project.

By analysing the data from the taken sample quantitatively, it is aimed to find out among others: the type of design changes that occurred most and the usage of BIM per discipline and per project. As the latter could not be traced from documentation, additional interviews are held with closed-ended questions. Hereby it is asked whether each change is modelled in BIM and to what extent.

3.5 Representation of results

Per case, an overall review is given on how design changes are implemented using BIM, together with all findings from the interviews. Also, the results of the sample analysis are described. After review of each case, cross-case analysis is performed to compare the results. This analysis is illustrated in two sections: ‘Technical dimension: product’ and ‘Organisational dimension: process’. In both parts, pitfalls in the project and areas of improvement are illustrated. Hereby, also is indicated what can be learned from the project. The technical dimension is about the usage and user-friendliness of BIM3D. The organisational dimension is about the process and collaboration within the project team related to design change.

3.6 Representation of procedure

The procedure shows how to implement design change with the use of BIM, during the execution phase of infrastructural projects. This procedure is a step-by-step approach, which is based on the combination of current literature, and also on the insight obtained during the analysis of the case studies.

This step-by-step approach is represented graphically through a flowchart. This flowchart also contains descriptions at each step for further explanation. By this procedure, the project team gains a full understanding of how the design change process should proceed and which actions they have to take for effective implementation of design change with using BIM.

Both the technical and the organisational dimension are represented in this procedure:

- Product(technical dimension): The use of BIM products during the implementation of design change.
- Process(organisational dimension): Description and visualisation of the process of design change, namely from identification to implementation with the use of BIM.

This procedure includes the process of how a design change is requested and approved. It describes how the project team has to share their information, which information should be shared by whom in which step of this design change process and who is responsible for correct handling of each step. The associated planning and costs (in BIM 4D & 5D) should change together with a design change. Information that is needed in order to adjust the model in 4D & 5D is included in the approach. How the data should be implemented in 4D and 5D is not further elaborated on.

3.7 Validation method of procedure

A validation session is organised with an expert assessment to ensure the applicability of the procedure within BAM. The experts participating in this session are not involved in this study beforehand. By inviting different experts within the infrastructure field, the validation outcome is expected to be more reliable. This group consisted of Contract Managers, a BIM manager, and design leaders of different infrastructure disciplines. All these experts work for the contractor BAM.

In total, seven persons participated in this session. One week before the validation session, the description of the procedure is sent to the participants. At the start of the validation session, an overview is given of the procedure. On beforehand, the flowchart is cut into parts, and per part, this is presented in more detail to the group. The participants then assess each part and give comments through an Excel document. This way, all opinions are treated equally. After gathering of all comments, a discussion is initiated to gain a better understanding of the argumentation of comments.

04

Case studies

In the last chapter, the research method is described. Hereby, it is indicated that besides a qualitative analysis, also a quantitative analysis is carried out. For the latter, a strategic sample is taken. In this chapter, it is highlighted how the samples are created from available data and how these are further analysed. Furthermore, an overview is given of the analysis and results of the case studies are presented in both the organisational and the technical dimension. In the end, a conclusion is provided of the case studies.

This chapter answers the following sub-research questions:

3. How is a design change currently implemented?
4. What is the current user-experience of the project team with BIM?

4.1 Sample of cases

For the quantitative analysis, a sample is taken from available data. In this chapter, the sample selection and sample analysis are described.

4.1.1 Sample selection

During the interviews, the design changes that are taken into account are determined. Different design changes occur during the execution phase of selected projects:

- **Deviations** are conditions on the building site, which are noticed by the contractor and are deviating from the own or supplied documentation. These might lead to design changes in the to-be-built design, and in most cases lead to a design change in the as-Built drawings. However, effects of deviations are difficult to measure, as there is little to no data available on this.
- **Notifications:** Design changes that do not lead to contractual changes and are initiated by the contractor (before approval of the design). Again, there is little to no data available on this type of design change.
- There are **contractual changes** which lead to design change: initiated by the client or the contractor. All data is available on these changes.

Often, deviations and notifications do not have a significant impact on the project constraints, as costs, time and quality. Conversely, contractual changes do have a significant impact.

The design changes have only been taken into account if they are completed or in progress. Design changes that are cancelled or still in concept phase are not included in this research as the first one is not implemented in the project and the second, because not much information is available.

As only contractual changes that lead to design changes are analysed, the register of contractual changes with corresponding change forms has been requested of concerned project teams. From this register, the contractual changes that are related to a design work package and the design changes at which the design change is implemented after the execution phase has started are selected. From the change form, all further information is gathered.
After pre-selection, the cases have the following amount of design changes to analyse:

Case A: 110
Case B: 71
Case C: 15

4.1.2 Data gathering of sample

In Appendix C, a table is given with all information gathered of the samples per case and the reasons for collecting the information. The most critical data gathered are:

- The cause of the change;
- The design disciplines that are involved in the change;
- Whether the change is implemented in BIM 3D;
- Whether work preparation and execution should take action, based on the change;
- The costs of the change;
- Whether a new planning is made because of the change.

The measured project constraints, as hard data, are time and costs. Both are traced from the documentation of the project. The impact of design changes could also be measured based on the quality of the deliverable, disruption of the construction process, or the number of elements to change in BIM. However, it is difficult to find data about the last mentioned.

Whether each design change is implemented in 3D and what type of change it was, is also analysed. This information is gathered from in-depth interviews, as this information is not available in any documentation. Also, the information on the time impact is collected from in-depth interviews. All these data is further analysed by using PowerBI, to look into correlations between the entered data. These data consist of both quantitative and categorical data. The latter has to be categorized.

4.1.3 Classification of categorical data

In order to perform an analysis and find correlations between variables, the categorical data has to be classified. After analysing the samples, the corresponding data and making use of the literature study, the causes of the design changes are categorised in the following types:

1. Client's change requests:
The client initiates these changes, and they represent additional needs and wishes for the project.

2. Partially incomplete or erroneous project documentation/requirements:
The client (or stakeholders of the client) deliver(s) a set of documentation and requirements at the start of the project. This documentation or requirements may be conflicting, incomplete or erroneous, which can lead to design changes. In practice, this often happens as the client also has time pressure and should hand over a lot of information within a short period during the tender. Moreover, as construction projects are rather complicated, some information might be unknown in an early stage of the project.

3. Contractor's change requests:
These changes are initiated by the contractor and are often mentioned as 'optimisations of the design'. These optimisations should ensure easier operations and higher income for the contractor.

4. Change of regulations:
This change can be initiated both by the contractor as by the client. Regulations are set up by governing parties. In case of change of regulations, projects may adopt these, and in certain cases, they have to adopt the new regulations.

5. Site-related changes:
These changes include circumstances as unforeseen ground conditions and site restrictions due to, e.g. difficulty in site acquisition. In case that incorrect information is handed over by the

client about the ground or site conditions, these changes are also categorised in site-related changes.

The reason that contractual changes are related to a design work package are as follows:
- An impact analysis has to be conducted;
- A change has to be implemented into the design;
- Phasing of design activities has to be changed.

These may co-occur within one design change. Another change reason is only changing or further elaborating of scope requirements.

Other classifications can be found in Appendix C.

4.2 Results of cases

In this chapter, the results of all cases are described. These results are divided into the organisational and technical dimension. In the organisational dimension, the design changes in the case, the design change process, and the consequences of design change are described. In terms of technical dimension, the value of BIM according to interviewees and the use of BIM per discipline are described. The reference system used in this chapter can be found in Appendix D. Additional information about the cases can be found in Appendix E.

4.2.1 Case A

Table 3 Project Information Case A

Type of project:	Infrastructure
Client:	Confidential
Contractor:	BAM Infra & Partner
Disciplines:	Civil Engineering, Roads, MEP (Mechanical, Electrical & Plumbing)
Start Design:	Confidential (year 0)
Start Execution:	Confidential
Finish project:	Confidential

4.2.1.1 Case analysis – Organisational Dimension case A

As of March 2019, 259 contractual changes are current or completed. Hereof 120 changes (46%) have had an impact on the design, of which 110 were analysed in total. The design changes in which the change proposals before the execution phase have been signed or for which less data is available have been omitted.

Design change:

The analysed design changes are related to a design work package because:

- 85% concerned a change in the actual design;
- 6% of the changes involved an impact analysis;
- 4% counted for change in the phasing of activities;
- The remaining 5% was a further elaboration of a scope requirement.

None of the above-mentioned reasons co-occurred in a design change. Phasing of activities had the highest median for cost consequences in comparison with the other indicated reasons. In 45% of the changes, discipline Roads was involved, see Figure 3. However, the highest costs are related to discipline MEP, see Figure 4.

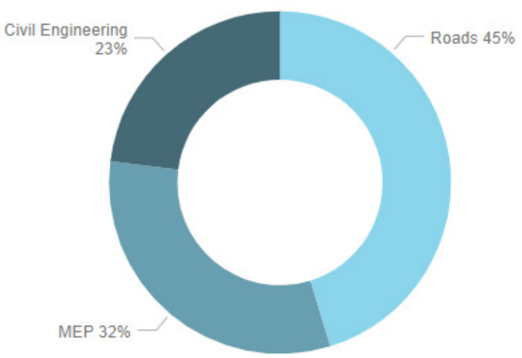


Figure 3. Share of Disciplines in case A

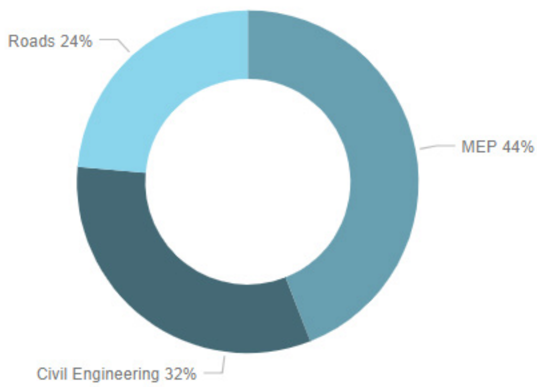


Figure 4. Costs involved per discipline in case A

According to the contract manager, contractual changes may have a substantial effect on the project constraints. However, it is possible that a contractual change does not have financial consequences. Then, it is often a further elaboration of the scope requirement. However, there is always a time consequence, as the process is disturbed and activities may be shifted, or new activities should be included in the planning[nCM-A1].

The contractual changes are initiated both by the client and the contractor. In the case of optimisations of the design (often to reduce costs), one should realise that the process will be disturbed and additional work also can lead to more costs[nCM-A1].

This case has a Design and Construct contract, and both DO, and UO are submitted to be reviewed by the client. All drawings become part of the contract when the client accepts the documents. Per design work package, the DO or UO is submitted. Every design change after approval of the UO will be a contractual change, as it already became a part of the contract. The client may reject a change proposal of the contractor after approval, but this is rarely done in practice[CM-A1].

Design change process:

A change proposal should be handed in by the client or the project team of the contractor. Then, the contract manager assesses the change and estimates cost and time consequences together with the cost manager and planner. Also, the part of the scope that will be affected by the change is determined and filled in the form. If both parties sign this change proposal with cost and time estimation, then it is almost certain that the change will be implemented in the project[CM-A1].

Before the final contractual change form is signed, there is often a negotiation about the costs. In practice, it happens that changes are already implemented in the project after signing the change proposal. Formally, the change should not be implemented before the final contractual change form is signed. However, if the project team is almost sure that the change is going to proceed, the change is already implemented in the design to prevent time delay. As part of the scope that is affected is already included in the change proposal: the requirements in Relatics can be adjusted and extended if necessary. A disadvantage of implementing change without everything formalised is that if the change is cancelled, the design must be reversed. This is a considerable risk and leads to extra manhours and thus, additional costs[CM-A1].

Meetings:

Every four weeks, there is a meeting with the client related to contractual changes. The two contract managers have a 2-weekly meeting with each discipline[CM-A1]. In these meetings, consequences of the change, the (adapted) requirements of the client, and how one should proceed with the change is discussed. If it is a minor design change, the change is immediately shared with design managers after signing the change proposal.

During the design phase, every week a meeting was scheduled for the BIM3D modellers so that they could gain insight into the whole design, the interfaces and whether the modellers needed information of each other. If necessary, 3D modellers took part in the 4D meetings[BM-A2]. Clash-detections were not organised very often. The clash sessions with all disciplines included were at most one per month during the design phase. At the moment, there is no BIM coordinator, and no clash sessions are performed[BM-A2].

Causes of change:

The share of involved disciplines per cause differs considerably. The share of disciplines involved per cause are shown in Figure 5. Hereby, most occurring causes, in this case, are Client’s change requests, Contractors change request and Partially incomplete or erroneous information.

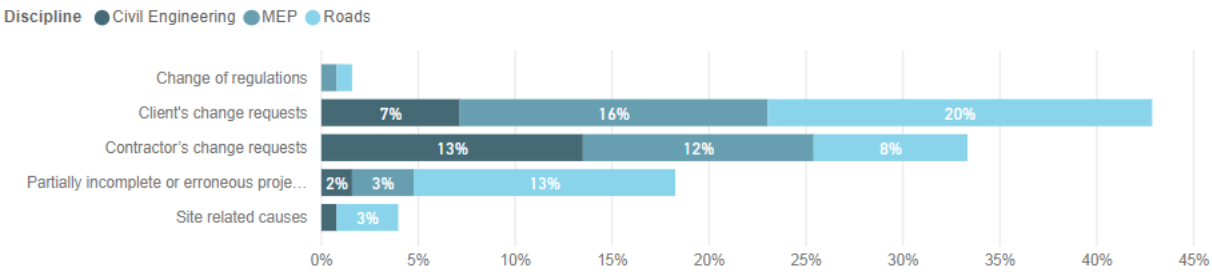


Figure 5. The share of design disciplines per cause in case A.

Consequences of design change:

As earlier mentioned, design change may have financial repercussions and has indeed implications for the planning as something has to change and extra time and work is required to implement this. Furthermore, because of the changes, there is less slack in the planning, the process of the work is disturbed. However, in most change (proposal) forms, it is stated that there are no time consequences, as the client understands time consequences as delay of the delivery date of the project[nCM-A1].

The contract manager mentions that each change should be implemented in the planning, but this requires high detailed planning. Now, this is not the case for the design work packages. In this case, the planning is only updated if it concerns execution activities or new scope. As design activities are challenging to assess on duration, the planning is not updated for changes that only concern design work packages and do not have impact on the work preparation or execution work packages[nCM-A1].

Together all design changes from this sample count for 4% of the total contract price. Per March 2019, except for one design change, there were no consequences for the delivery date of the project. As these concerned changes were not part of the critical path, these could be included in the slack of the planning[nCM-A1].

In 49% of the changes, a new planning is done. This concerned mainly clients change requests (65%), and the remaining part concerns: contractor's change request(15%), partially incomplete documentation(15%), site-related(6%). If execution work is included in the change, then a new planning is done in 63% of the changes.

Documentation of design change:

All 'deviations' and 'notifications' are included in Relatics by the project team. The contract managers administer the contractual changes. In certain cases, the project team does not recognise a design change that may lead to a contractual change. Then, a design change is implemented without consulting the contract manager and the client. This means that this change is not included in Relatics, but only in the design[CM-A1]. Design changes are documented in a log by Autodesk Revit. However, it is not readable[BM-A2].

4.2.1.2 Case Analysis – Technical Dimension case A

In this section, an overview is given of what is understood by BIM 3D, to what extent 3D modelling is used (per discipline) and how interfaces are solved.

BIM definition

The contract manager defines BIM as a clash detection tool, which should be used by each modeller and thus by each discipline. Otherwise, problems can occur in the drawings or even during construction[CM-A1].

The BIM modeller defines BIM as a 3D model, at which information is linked to each object. BIM is not only used for drawings, but also 4D simulations and quantities. The modeller thinks that in the future BIM will be an extensive database, where all information is linked together: requirements, documents, 3D model and all other information. For now, technically, this is not possible it was said [BM-A2].

BIM Usage:

BIM usage differs between and within the design disciplines. Some members of the project team are reluctant to work with BIM, as they are having difficulties with the software. There should be a culture change: from 2D to 3D BIM. Project team members have to think in 3D, not in 2D drawings[BM-A2]. The BIM modellers do have the knowledge to work with the software. However, they should be aware that they should also change the linked information when they change something in the design. That can be difficult for the modellers, who switched recently from AutoCAD to 3D [BM-A2].

In this case, 2D drawings are taken as a primary source, as all information is visible in 2D, but not everything is modelled in 3D[DM-A5]. Everything that is modelled in 3D ends up in 2D drawings. The 4D model is modelled once for the critical parts of the work and is not updated after that. If a design change concerned an impact analysis, phasing of activities or further elaboration of a requirement, these are not modelled in 3D nor 4D. Often 2D is used for these purposes. In Table 4, an overview is given of BIM usage per discipline.

Table 4. BIM usage per discipline in case A

Discipline	Geometry in 3D	Details in 3D	Interfaces in 3D
Civil Engineering	+	+/-	+/-
Roads	+/-	-	-
MEP	+/-	+/-	+/-

Use of BIM3D - Civil Engineering

Civil Engineering has 3 models in Revit. One of the models is modelled externally by the architects. Changes during Execution design(UO) are often drawn in 2D, as the reinforcement is drawn in Jakarta. Otherwise, a 3D model with the change implemented should be sent to Jakarta, and there they have to change their model. This takes more time, and it has been said that communication is easier if the team is at the same location. Therefore, the change is implemented in 2D.

Furthermore, many details are drawn in 2D and collected in a detail book. In this collection, details are included which are missing in the 3D model. This applies among others to a part of the reinforcement drawings and joint profiles. The most complicated part of the reinforcement is drawn in 2D, as most reinforcement drafters did not have any experience in 3D. Hereafter, a large part of the 2D details is adopted in the 3D model by a modeller. However, there is still a part drawn in 2D. In the 3D model, if details of objects are missing, no references to the 2D detail are given[nBM-A2].

The Civil engineering modeller acknowledges that first drawing in 2D and then copying to the 3D model is double work. ‘’Everything in 2D should have been in 3D for information to the other disciplines.’’ [nBM-A2]

Use of BIM3D - Roads

Road design uses MX Road to implement their design in 3D and AutoCAD to draw details in 2D. Thus details are not taken from the 3D model. The changes in specifications (material or properties) are not visible in the 3D model, as these are drawn in 2D. In 3D, the geometry and position of the roads and site are modelled (parametrised). Design changes that concern other types within this discipline are drawn in 2D, and do therefore not end up in the 3D coordination model. With other types is meant among others: sewerage, wells, weirs, trees, cables. Also, in case of an impact analysis, 3D is not used. If a design change concerns the geometry of the road, first 3D is used. However, 2D is still used, after that, to draw the details of this change.

It is possible also to link an object to the material in MX Roads. However, the modeller said that this is complex and time-consuming as materials of roads differ in each section of the road and change often during the project.[BM-A3]

Use of BIM3D - MEP

There is one 3D model in Revit for this discipline. The cable routing, schematics (detailed view of all installations and conceptual view of the energy system) are not visible in 3D. These are drawn in 2D in e-plan. The cabinets for the electronics are modelled in 3D. The content of these cabinets is drawn in 2D.

Specifications of objects are not always implemented, such as lighting classes of luminaries. The interviewee indicates that these properties of luminaires can be indicated in 3D, but it is too much work afterwards since the manufacturer of the luminaires is not known at the start of the project.[BM-A4]

BIM3D usage during implementation of design change

In total, the share of implemented design changes is illustrated in Figure 6. Of all design changes, 25% is wholly implemented in 3D. If only is looked at design changes, at which a change was in the actual design, thus eliminating other consequences, then the amount of changes that are implemented in 3D increases instead: 29% then is wholly implemented in BIM3D. However, the amount of design changes implemented in BIM3D differs per discipline. Civil Engineering implements changes most often in 3D, then MEP. Roads only implements changes partially in 3D; details are drawn in 2D. And there is a positive correlation between costs of the change and use of BIM 3D: The higher the value of the change, the higher the chance that it is modelled in BIM 3D.

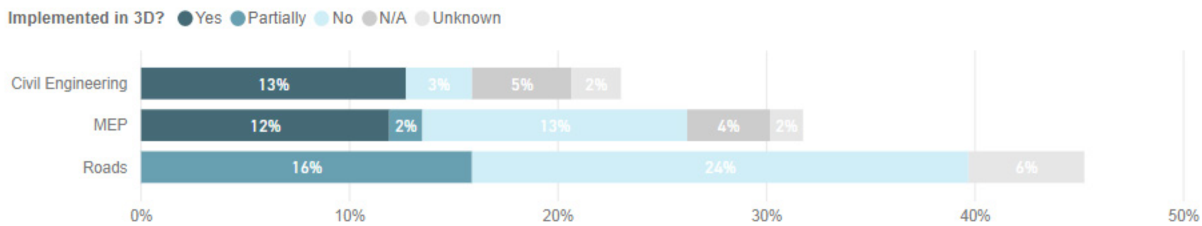


Figure 6 Implementation of design changes in BIM3D per discipline in case A.

Interfaces and clashes:

Worksets are used within this project. As Civil Engineering and MEP both work in Revit, it is easier to exchange data. Both disciplines link each other’s model in their model as worksets. The models are updated by the modellers each day. Roads are also linked as a workset, partly as 2D and 3D. Hereby BIM 360 is used to realise this[BM-A4].

On the contrary, modellers of the discipline Road only work with their own model. They do not load any model into theirs as a workset. The modellers of the road design have no permissions to enter the Revit models, as they have no knowledge of that software. So, to gain insight into the interfaces, Navisworks is used to look into the coordination model. However, one cannot work or model elements in Navisworks[BM-A2].

Another mentioned problem is the reluctance in releasing sub-models by discipline Roads, which leads to outdated models[BM-A2]. In this case, also MEP started late to work in 3D, which resulted in changes in recesses in the concrete that was modelled by Civil Engineering.

If a modeller encounters a clash within the discipline, then he informs the other modellers and possibly his design manager. If it is a clash with another discipline, the modeller reports this to the design manager, and the design manager then discusses the clash with the design manager in case[BM-A2].

4.2.2 Case B

Table 5. Project Information case B

Type of project:	Infrastructure
Client:	Confidential
Contractor:	BAM Infra
Disciplines:	Civil Engineering, Roads, Rail, A&M (Architecture and Mechanical), E&P(Electrical & Plumbing)
Start Design:	Confidential (year 0)
Start Execution:	Confidential
Finish project:	Confidential

4.2.2.1 Case analysis – Organisational dimension case B

As of March 2019, 238 contractual changes are current or completed. Hereof 87 changes (37%) have had an impact on the design, of which 71 were analysed in total. The design changes in which change is initiated before the execution phase or are still in concept phase have been omitted.

Design change definition:

In this case, a change is only marked as a contractual change if the change has a financial impact for the client. Otherwise, the economic implications are 'failure costs' of the contractor. In this case, deviations are also changes that are initiated by the contractor and which do not have financial consequences for the client. The contract manager mentioned that a deviation requires less administration than a contractual change. Therefore, it has been decided to limit the number of contractual changes and only to include changes that have a financial consequence for the client[CM-B1].

In 96% of the design changes, it concerned a change in the actual design. 11% of the changes concerned an impact analysis. These also occurred together. The distribution of the disciplines over the changes is as follows:

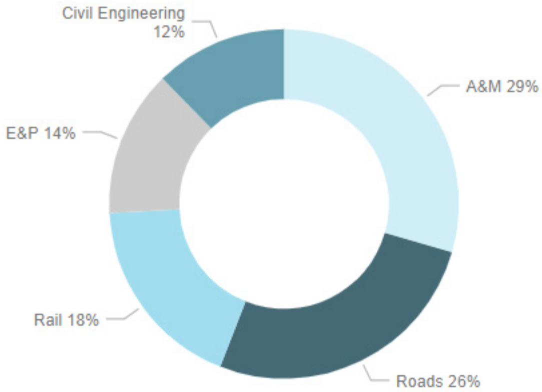


Figure 7. Share of disciplines in case B.

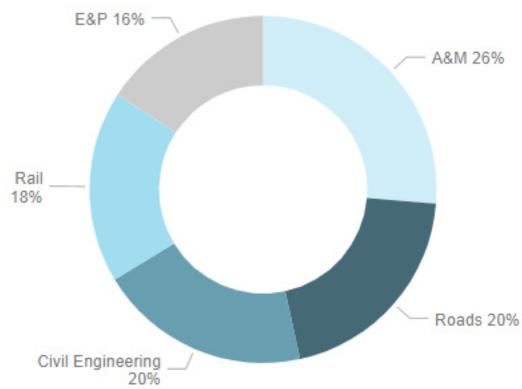


Figure 8. Share of costs per discipline in case B.

A&M has the highest share within costs, namely 26%, see Figure 8. Hereafter comes Roads, Civil Engineering, Rail, and E&P. It is remarkable that Civil Engineering has a relatively low share in the changes; however, a high percentage in the costs, see Figure 7.

Design change process:

A change proposal should be handed in by the client. Then, it is included in the table of changes. If the change has an impact on the design, the change is communicated to the design manager and relevant design leaders. These design changes are immediately implemented after it is certain that it concerns a contractual change. In the case of multidisciplinary changes, first, an integral meeting is initiated. If the contract manager thinks that, after assessing the change, an impact analysis is required before implementing the change, then the change is not immediately implemented. However, this was not often the case. Simultaneously with the implementation of the design change, the scope and costs of the change are discussed[CM-B1].

The project team of the contractor can also initiate changes. Then it is communicated to the contract manager so that he can assess whether it is a contractual change. If so, the change is discussed with the client, and the design change will be implemented in parallel with the financial negotiations with the client[CM-B1].

Meetings:

In the case of multidisciplinary design changes, meetings are initiated within the project team. Other changes are resolved within the own team. Every two weeks, there are technical consultations with the client. Hereby also changes were discussed. In the meantime, these meetings are mainly used to address the financial consequences of the changes[CM-B1].

Clash detections were organised every two weeks, but that turned out to be too often because the design changed frequently. So it was decided to perform a clash detection on every part that was going to be sent to Jakarta for the 3D reinforcement drawings[CM-B1].

Causes of design change:

The share of involved disciplines per cause differs considerably. The percentage of disciplines involved per cause are shown in Figure 9. Hereby, Clients change requests, and Partially incomplete or erroneous documentation are most common.

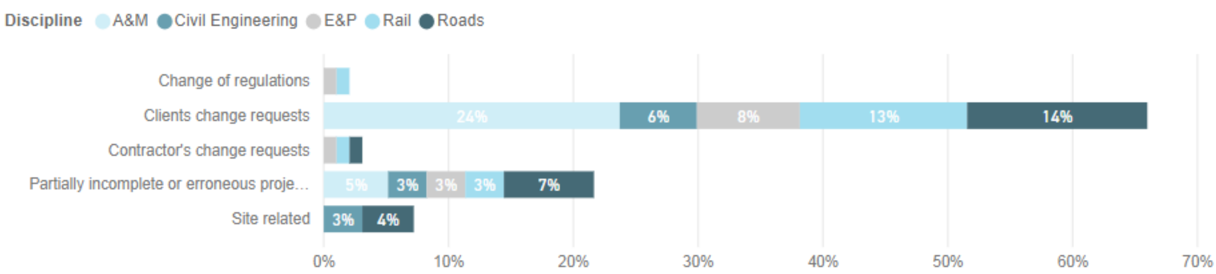


Figure 9. Share of design disciplines per cause in case B.

Consequences of design change:

The changes from the sample cost together 3.8% of the contractual value. Per March 2019, there were no consequences for the delivery date of the project. As these concerned changes were not part of the critical path, these could be included in the slack of the planning[nCM-B1]. Only for one design change, the time-impact is analysed. Adjustment to the planning was not found necessary.

Documentation of design change:

Deviations are included in Relatics. However, contractual changes are documented in Excel; the project team has no access to this information[CM-B1]. The log in Revit of design changes is not readable. Modellers keep a record of design changes, however not consequently[BM-02].

4.2.2.2 Case Analysis – Technical Dimension case B

BIM definition:

The added value of BIM is that it can be used for 3D and 4D modelling. In 3D, it is possible to integrate various designs of each discipline and to perform a clash detection to improve the quality of the design. 4D gives insight in the construction sequence, which can be a tool for certain complex parts of the work[CM-B1].

A way of working together to exchange information unambiguously. The future vision is that you have a good database where you can store information, where both calculation, planning and design can extract their data. At this moment, the system is document-driven. The ideal situation with an information model is a data-driven or object driven environment[BM-02]."

Other definitions given are that BIM3D is used to detect clashes[BM-B4; BM-B5; BM-B7], to visualise [BM-B4; BM-B5] and to process information [BM-B5; BM-B7]. All information should be linked together in order to form a Building information Model[BM-B7].

BIM Usage:

The BIM model exists of more than 50 sub-models. The project is cut into small parts to keep it manageable. This way, every small part can be released apart from each other. BIM3D modellers have access to all these sub-models. Meanwhile, site managers have limited permissions: They only can view the model and cannot edit[BM-B2]. The 4D model is modelled once for the construction pit in Navisworks. This 4D simulation is used by the work preparation department to align with the subcontractors and by the site managers.

In Table 6, an overview is given of BIM usage per discipline.

Table 6. BIM usage per discipline in case B

Discipline	Geometry in 3D	Details in 3D	Interfaces in 3D
Civil Engineering	+	+	+/-
Roads	+/-	-	-
A&M (Architecture & Mechanical)	+	+	+/-
Rail	+	-	-
E&P (Electrical & Plumbing)	-	-	-

Use of BIM3D - Civil Engineering

Civil Engineering models mainly in 3D, even the details are modelled. Only details of trees are drawn in 2D. Temporary facilities are not always modelled in BIM3D. This depends on the number of interfaces with other disciplines. Civil engineering had to change its design often during this project, because of changes in the Road design.

Use of BIM3D – Roads:

In the 3D coordination model, an outdated version of the Roads model is visible. This Roads model includes only the geometry; no details are available. As from June year 1, no more budget was available for 3D modelling; the team continued to draw in AutoCAD. Now and then, Civil3D is used to create 2D drawings for a part of the project. This adjusted 3D model is not used for information exchange with other disciplines, as it is not complete. In addition, because both 2D and 3D are used, both might contain incomplete information. Details are not modelled in 3D, as there was no time and budget for this[BM-B4].

Use of BIM3D – A&M (Architecture & Mechanical)

This discipline uses BIM3D to model their design, including details. If details are not modelled, a parallel flow is created[BM-B5]. Temporary facilities are not modelled in 3D[BM-B5]. In some cases, the supplier draws a detail in 2D for a temporary facility, to be used by the site manager.

Use of BIM3D – Rail:

Only the geometry is modelled in Civil3D within the discipline Rail. Except for the dimensions and the coordinates, no other information is linked to the 3D model. Thus, all details and installation diagrams are drawn in 2D in AutoCAD. The reason that details are drawn in 2D is that the object library is minimal, mainly for the security objects. Suppliers do not provide 3D objects of their products and building the library does not outweigh the costs. Since Prorail does not ask for a 3D model, there is no time and money to invest in the object library and the 3D model[BM-B7].

Use of BIM3D – E&P (Electrical & Plumbing):

Electrical & Plumbing do not work in BIM; in the model, one block is reserved for this discipline[BM-B2]. Only the put wells are modelled in 3D by the modellers of A&M, as there were interfaces with the surroundings[BM-B6]. After modelling in 3D, A&M passed the 2D drawings taken from the model to E&P, so they could work on it further. The design of E&P must be implemented in 3D, as it has many interfaces with A&M[BM-B5].

BIM3D usage during implementation of design change

In total, the share of implemented design changes is illustrated in Figure 10. Of all design changes, 30% have been completely implemented in 3D. However, the amount of design changes implemented in BIM3D differs per discipline. A&M implements changes most often in 3D, then Civil Engineering. Roads and Rail only implements changes partially in 3D; details are drawn in 2D.

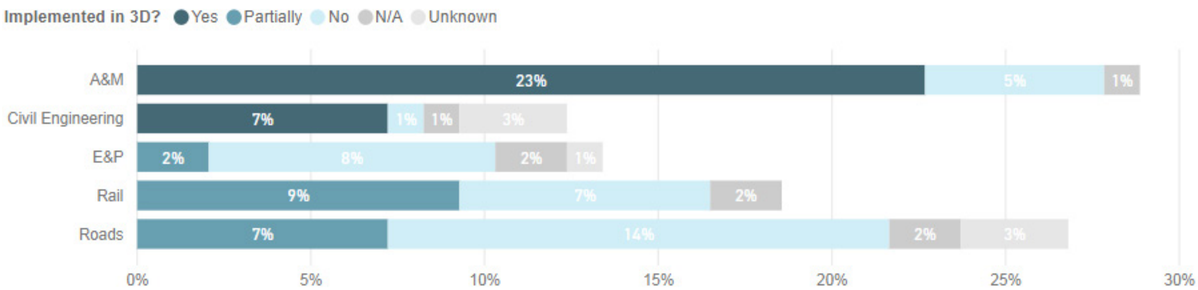


Figure 10 Implementation of design changes in BIM3D in case B.

Interfaces and clashes:

The more than 50 sub-models are all linked as worksets in the Revit Model, so interfaces are visible. The Civil3D model is also apparent in Revit [BM-B2]. Hereby, a Central File is used. Modellers can work simultaneously in the same model. However, Rail and Roads cannot see the other disciplines in Civil3D.

In case of a design change with interfaces with one or more disciplines, the change is completely modelled in 3D by only one of the affected disciplines. If there is a clash with another discipline, modellers may mutually solve this. If it is a more significant clash, design leaders are included in the process.

The interfaces with Roads that are visible in the coordination model may be incorrect as discipline Roads did not upload any 3D model after June year 1. Because of the outdated 3D model for Roads, 2D drafters of this discipline tried to find and solve clashes without the automatic clash detection [BM-B4].

The 3D coordination model can be viewed in Navisworks. This is user-friendly[BM-B4] and serves to provide information to the project team[BM-B2]. However, if information from one or more disciplines is missing or outdated, then the coordination model has little use[BM-B4]. Also, the team should realise that the Navisworks model is a moment display; the design is going on[BM-B7].

It may occur that 2D drawings are not corresponding with the 3D model. Then, one of the two contains the latest version. This can happen because of:

- A change in the design that is implemented in 2D or 3D;
- Some disciplines do not use 3D;
- 3D may not be used if there is a time shortage and execution date is approaching. This only applies to deviations, not to contractual changes[BM-B3].

4.2.3 Case C

Table 7. Project Information case C

Type of project:	Infrastructure
Client:	Confidential
Contractor:	BAM Infra
Disciplines:	Temporary Facilities, Civil Engineering, Rail, Roads
Start Design:	Confidential (year 0)
Start Execution:	Confidential
Finish project:	Confidential

4.2.3.1 Case Analysis – Organisational Dimension case C

As of March 2019, 78 contractual changes are current or completed. Hereof 16 changes (21%) have had an impact on the design, of which 15 were analysed in total. The design changes in which the first change forms before the execution phase have been returned have been omitted.

Design change definition:

Most design changes are registered as deviations in this case. If a deviation cannot be corrected with a measurement and there is a deviation from the contract, then it becomes a contractual change. In 93% of the design changes of the sample, it concerned a change in the actual design. 13% concerned an impact analysis. And 20%: phasing of activities. The disciplines are distributed over the changes as follows:

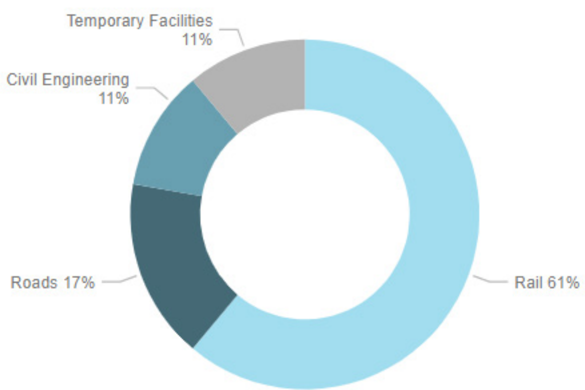


Figure 11. Share of disciplines in case C.

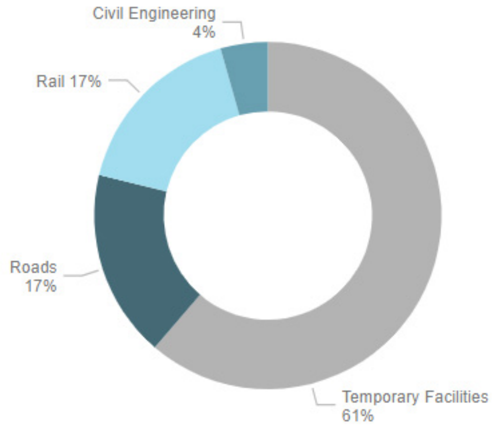


Figure 12. Costs per discipline in case C.

Rail was involved in most changes, see Figure 11. The two changes in which Temporary Facilities have been affected, have together the highest share within the overall costs, see Figure 12.

Design change process:

The design changes were often identified by the contractor and passed on to the client. Then, the client assessed the change and both parties performed an impact analysis. In most cases, the change proposal is drafted by the contractor. Hereby, an estimation is given of consequences of the change: in time and costs. After approval, the design change was implemented by the design team. Simultaneously, the financial negotiations took place.

The client requested design changes often during meetings with the design manager. The design manager determined the interfaces, and together with the contract manager, the impact of the design change were assessed.

Meetings:
Every four weeks, there were change control meetings with the client. All current changes were discussed during these meetings. The progress of the changes was communicated almost daily to the client. Within the project team, meetings were initiated in case of complex or multidisciplinary changes.

Causes of design change:
Often changes are initiated because of incomplete or erroneous project documentation and requirements, which are delivered by the client. This is only found out when working out the contract into detail within the design, close to the execution phase. Site-related changes also occur, often undocumented cables and deviations in the ground. These causes are hard to avoid, because of the time pressure and because there is no design in the tender phase[CM-C1; DM-C2]. Other causes named by the design manager: new wishes of the client, change of regulations.

The share of involved disciplines per cause differs considerably. The percentage of disciplines involved per cause are shown in Figure 13. Hereby Clients change requests, and Partially incomplete or erroneous documentation are most common.

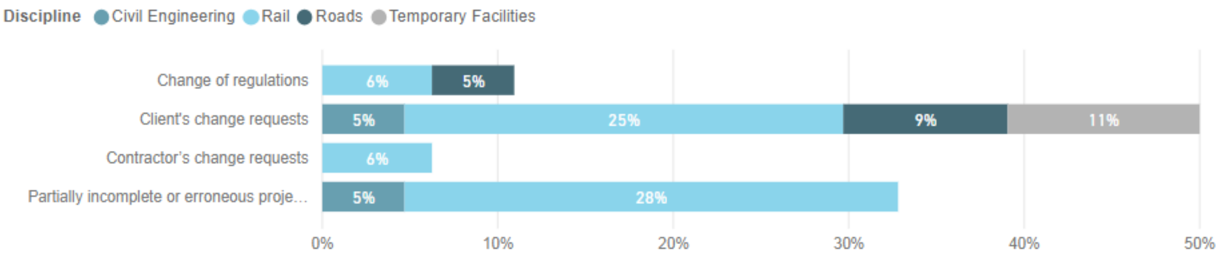


Figure 13. The share of design disciplines per cause in case C.

Consequences of design change:
Design changes may have affect time, costs and quality[CM-C1]. Furthermore, the process is disturbed, and because of all interfaces, the effects are often more significant than previously thought. Also, communication problems arise if the model is already sent to BAM Infraconsult in Jakarta[DM-C2]. In this case, the 15 changes together cost 3.8% of the total contract value, and the planning is adjusted in 6 of the 15 changes.

Documentation of design change:
Changes are registered in Relatics, together with corresponding requirement changes.

4.2.3.2 Case analysis- Technical Dimension case C

BIM definition
A model which contains all information related to the design. This Building Information model may be used during decision making [CM-C1].

BIM is a tool that is used to control the design process and the project. Design managers can see the design in 3D, whether the model contains clashes and if it will fit in the execution phase. BIM may also be helpful for site managers in order to understand the design solutions. Hereby, both Relatics and Thinkproject are part of BIM[DM-C2].

BIM Usage
The BIM model consists of 5 sub-models. These are clustered in Navisworks. The sub-models were grouped to a coordination model at least every 3 weeks. This coordination model was

used as an information source to the team, to perform clash detections, to simulate a safety walk and to simulate sightlines for train signals[DM-C2]. There was one modeller for Civil Engineering, Roads also had one modeller, and Rail had six 2D drafters. E&P is part of Rail in this case.

The 4D model is modelled once and not updated after that. Apart from the modellers, the project team had no permissions to enter the BIM3D models.

In Table 8, an overview is given of BIM usage per discipline in case C.

Table 8. BIM usage per discipline in case C.

Discipline	Geometry in 3D	Details in 3D	Interfaces in 3D
Civil Engineering	+	+/-	+/-
Roads	+/-	+/-	+/-
Rail	+/-	+/-	+/-
Temporary facilities	+/-	+/-	+/-

BIM Usage Civil Engineering:
Civil Engineering modelled mainly in 3D. This applies for the geometry and details. The last details that had to be made are drawn in 2D[nDM-C2].

BIM Usage Roads:
Roads also mainly modelled in 3D[nDM-C2].

BIM Usage Rail:
Every object that had interfaces with another discipline is modelled in 3D, the rest in 2D. Details are drawn in 2D. Sightlines are checked within the 3D model[nDM-C2].

BIM Usage Temporary Facilities:
Only the geometry of the temporary auxiliary bridges and abutments were modelled in 3D. As interfaces were clear of other temporary facilities, they have been drawn in 2D[nDM-C2].

BIM3D usage during implementation of design change
In total, 39% of the design changes have been fully implemented in BIM3D, see Figure 14.

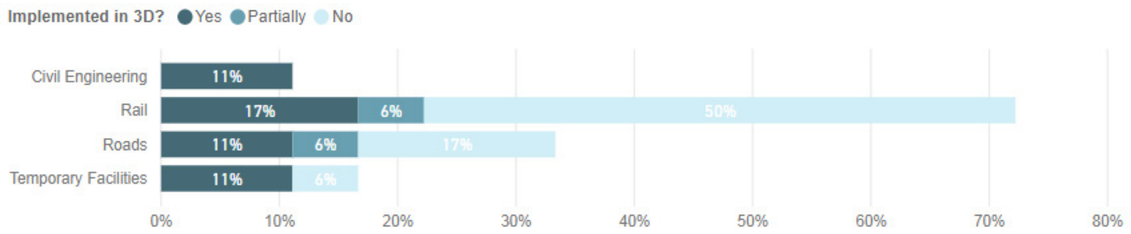


Figure 14. Implementation of design changes in BIM3D, per discipline, in case C.

Interfaces:
During this project, approximately 10 clash detections have been carried out, only on the critical parts. Hereby clashes are found or gaps in the design. The clash sessions took place before DO and UO. Most interfaces were visible for all disciplines, as they imported other models in their own model. However, this was updated manually once per week or per 2 weeks. This resulted in outdated information. In case of multidisciplinary design changes, one of the disciplines took the lead, and the design was implemented parallel with affected disciplines[nDM-C2].

4.3 Cross case analysis

In section 4.2, the results of all cases are described. In this section, the similarities and differences across these cases are explored and presented. Hereby, also insights of the literature study are compared to findings from the case study. As in the last section, the organisational dimension and the technical dimension are both reviewed. Both have a user-dimension. Hereby, users are members of the project team that are involved in the change process. The users have to, among others, use BIM software and have to follow the procedures that are being structured by one or more users. In this section, it is also reviewed what effects users had on certain aspects in both the organisational and technical dimension.

4.3.1 Organisational dimension - Process

Change Process

The change process of each case is defined by the project team in their own PMI. In the PMI, all processes of BAM Infra are included. The contractor has a generic change process for both client change requests and contractors change request. However, these are first changed before usage. This is inefficient and creates confusion for project teams. Thereby, the change processes are not complete. The processes end with that the change has to be implemented. How the change should be implemented is not further elaborated on. There are specific processes that show how to proceed with among other verification processes, design processes, clash detections. However, these are all separate processes, and BIM is not integrated.

In Figure 15, the design change process steps that are similar for the three cases are illustrated. First, a design change is requested by the client or a member of the project team. The client requests changes often per e-mail or during meetings. Requests from the project team often originate from design work or meetings. When the contract manager receives this request, he determines the type of design change, whether it is a contractual change and on whose responsibility this change will be implemented. Hereafter, the change is documented: In case A and C in Relatics. In case B, Excel is used. In the latter case, the documentation of changes were therefore not accessible for project team members. Simultaneously with documentation of the change, interfaces with disciplines are determined. Hereafter, effects on time and costs are determined together with the planner and cost manager. If both parties agree on the scope of change and the cost estimation, the change proposal is signed in case A. In case B and C, only a change proposal is shared. Hereafter, negotiations follow on both scope and mainly on costs to finalise the contractual change. If agreed, the final change form is signed by both parties. The order of informing the project team during the design change process is illustrated in Figure 16.

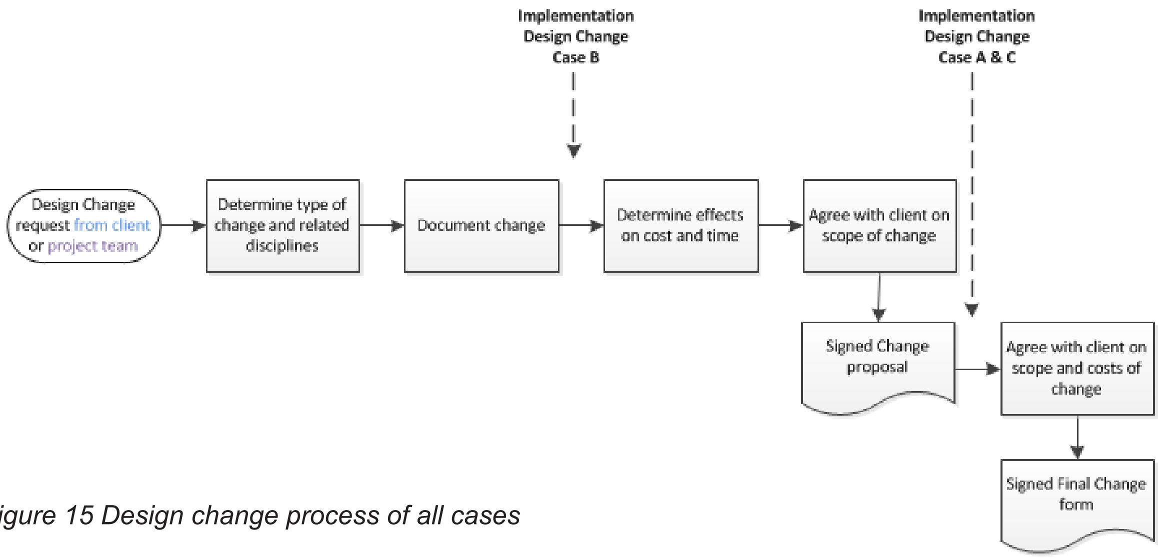


Figure 15 Design change process of all cases

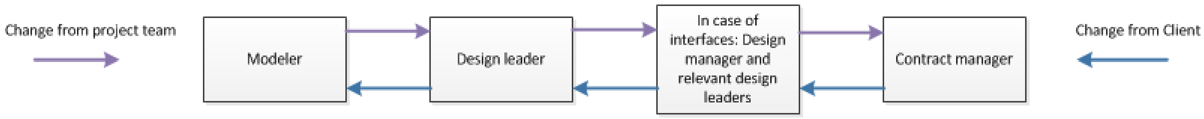


Figure 16. Order of informing project team during the change process.

Implementation of Change

In case B, the change is implemented in the design shortly after the change is requested. In case A and C, the implementation in the design is often after both parties have agreed on the scope, see Figure 15. In all cases, there is a risk that the client cancels the change as the final change form is not signed before implementation. In case B, this risk is more substantial as there is not even agreed on the scope of change and on a particular cost estimation. The time that elapses between formal notification of the design change and agreement on the change proposal has a median of 9 months in case A. In case B, this is 5 and in case C 1 month. However, in all cases, there are outliers up to a minimum of 20 months. This shows that it is not acceptable to not agree on both scope and costs before implementing the design change. In case that the client cancels a design change, the design should be reversed. This is costly and takes extra time. Additionally, the process is disturbed twice, as the design change first is implemented and then reversed.

Most changes occur during execution phase; this confirms what is stated in literature. For case A this is 92% of all design changes, case B 82% and case C 94%.

Causes of change

In all cases, risks are often not indicated in the change form and time effects are only shown if a delay in completion date is expected. How much time is needed to implement the change is not stated in these change forms. Clients change request is the most occurring cause for design change in all cases; this confirms what is said in literature. In Case A, this is 44%, Case B:66% and Case C:47%. These high percentages can be related to the fact that the client is not fully aware of the possible consequences of requested change. Also, clients change requests are rarely rejected by the contractor, as the contractor wants to make more profit on the project. In case A, contractors change request also occur often as a cause of design change(30%). This is also to have a higher income or to ensure easier operations. However, all parties should realize that implementing design changes disturb the process, have a time and cost impact and may create new risks. As indirect costs apply, the cost impact is hard to predetermine. Thus, the idea that the contractor can earn from a change must be abandoned, also according to interviewees. Furthermore, the underlying cause of contractors change request is not documented and therefore not known whether it is an optimization or a design error. It is self-evident that a design error leads to a change. However, this is often at the responsibility of the contractor and will thus, in most cases, not lead to a contractual change. As for optimizations, these should not necessarily be implemented. Design errors are not documented at the moment; this has to be done for complete documentation of the project and to prevent making the same mistakes in the design in the future.

Other causes of change were identified as Partially incomplete documentation, Change of regulations and Site-related changes. Regarding Partially incomplete documentation, this is the responsibility of the client and occurs most after client change requests. These documents are supplied during the Tender phase and are incomplete or include errors. The project team often discovers these during design work or meetings in the execution phase (case A). Discipline Roads had the most incomplete documentation in case A and in case B. In case C, this applies to discipline Rail.

Change of regulations did occur in all cases. However, this is not an often occurring cause: an average of 3,8%. Site-related changes are also the responsibility of the client, following the UAV-gc. This cause has an average of 3,4% of the design changes.

Consequences of Change

In order to gain insight into the implications of a change, impact analyses have to be carried out, as stated in literature. However, in most cases, an impact analysis is not done regularly; in only 10% of the design changes, the analysis is performed. Instead of an impact analysis, only cost consequences and time consequences are reviewed. Without looking at the impact on possible new risks, analyse the effort on (re)design and (re)construction, necessary measurements may not be taken, and the project team will eventually experience it while implementing the design change with possible negative consequences.

Regarding time consequences, these are only documented in a new planning in 49% of the changes in case A and 40% of the changes in case C. In case B: no planning is adjusted at all. This is remarkable, as each change has an impact on time, so the planning should be adjusted for each change. The choice not to make a planning was, e.g. that it is hard to predict how much time is needed for design work. Construction work, on the contrary, is easy to plan, according to interviewees. At the moment, it is not traceable which change is implemented precisely when and how much time was needed for design and work-preparation. Only the dates of change request, change proposal, and final change form are known. However, the changes were not always implemented after change proposal(in case A and C). If documented and tracked how much time was needed with the number of people working on the change, it will be easier to learn from it for future changes and projects. Furthermore, high-level schedules are needed to plan the design in detail, that is not the case at the moment.

Looking at the costs, Discipline MEP in case A has the highest costs for changes. In case B, this is Architecture & Mechanics, and in case C, this is Temporary facilities. The design changes during execution phase cost between the 3.8-4% of the contractual price. This applies for all three cases. It has to be said that case A and B are not yet completed and that the percentage may become higher at completion.

4.3.2 Technical Dimension – Product

Value of BIM

For all cases, it applies that members of the project team who are not using BIM3D, see the value of BIM3D mainly in clash detection. Integrating data and information is more often mentioned by team members who use BIM3D. Thus, not every member of the project team is well informed about this matter. The fact that design managers, in some cases, choose to have something drawn in 2D can be linked to proceeding. Design managers should realise that information will be missing in the Building Information Model, if they decide to have drawn particular objects or changes in 2D. Not only will the information be missing, also a parallel information flow is created, which can lead to errors and more changes afterwards. Every time something changes in 2D, the design team has also to check this change in 3D and vice versa. It occurs that the information presented on 2D drawings do not match with the data presented in the 3D model. Furthermore, the named double-check is impractical and time-consuming. However, remarkable is that design managers often choose to have parts of the design (changes) drawn in 2D, to prevent time delay. As knowledge is lacking to model the change in 3D in the same time as drawing in 2D, there is no added value to design every change in 3D according to some design leaders. This suggests that a culture change is needed.

BIM Plan

In both case A and C, a BIM plan is drafted. In case B, only a Revit Execution plan is written as there was no time and budget for this. It is crucial to enshrine agreements in a BIM plan so that the project team is aware of how BIM is used in the project. Hereby is indicated among others which software is used by which discipline, the Level of Development of sub-models, how data is stored and shared within the project.

BIM Usage (per case and discipline)

In Figure 17, an overview is given of BIM usage per case based on the samples that are analysed. In all cases, none of the design disciplines work ultimately in BIM3D. It is always a combination of using both 3D and 2D. Within infrastructure, the following disciplines are present: Civil Engineering, Roads, Rail, Architecture, and MEP(mechanical, electrical and plumbing systems). See Table 9, for all disciplines per case.

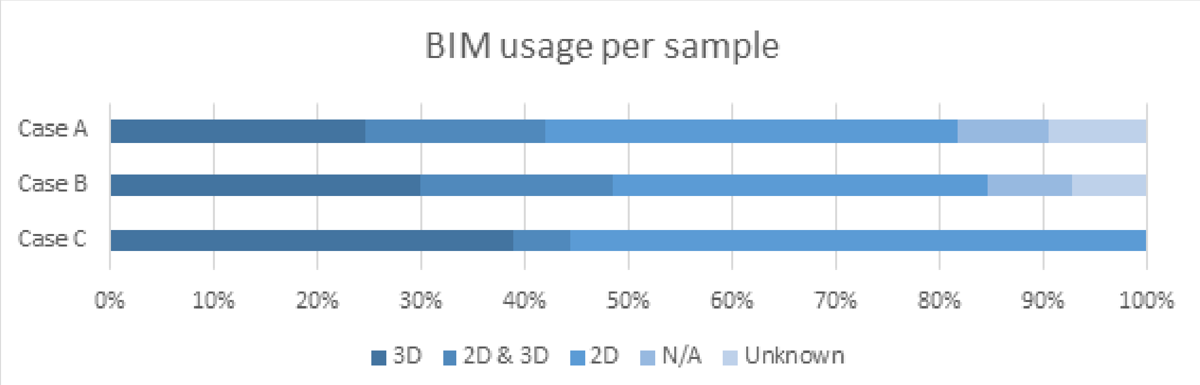


Figure 17 BIM usage for all cases per sample.

Table 9. The disciplines involved in all cases

Case A	Case B	Case C
Civil Engineering (incl. Architecture)	Civil Engineering	Civil Engineering
Roads	Roads	Roads
MEP	Rail	Rail (incl. Electrical & Plumbing)
	Architecture (incl. Mechanical)	Temporary facilities
	Electrical & Plumbing systems	

Discipline Civil Engineering

Civil Engineering at case A modelled at least 55% of the design changes entirely in 3D. 14% of the changes have been drawn in 2D, the remaining 31% was unknown or not applicable, i.e. no change had to be made to the design in 3D nor in 2D. From the interviews, it appeared that many details were also drawn in 2D. However, part of these details are adopted in 3D. Hereby, the reason to draw first in 2D was missing knowledge of the reinforcement drafters. Civil Engineering at case B modelled at least 58% in 3D, 8% in 2D and the remaining is unknown or N/A. In case C, the two changes of Civil Engineering were both modelled in 3D. For the discipline Civil Engineering, for all cases, the design changes mostly concern modifications in the geometry.

Discipline Roads

Discipline Roads models in all cases, mainly the outlines of the design in 3D. Information linked to the objects are coordination and geometry. Details are drawn in 2D. In case A, discipline Roads modelled 35% of the design changes partially in 3D, and 53% in 2D. In case B, the 3D model of the discipline Roads was not updated after one point, and the design team continued to work in AutoCAD. Hereafter, in some cases, the team modelled some objects in 3D to create 2D drawings. These created 3D models are only used to create 2D and are not adopted in the coordination model. In total, the design changes that were partially implemented in 3D are 27%, and 54% is implemented in 2D. The remaining 19% is unknown or N/A. In case C, 2 of the 5 design changes that concerned Roads were implemented entirely in 3D. 1 change was partially implemented, and 2 changes only implemented in 2D.

Discipline Architecture
Discipline Architecture is only a separate discipline in case B. Hereby, 79% of all design changes were implemented in 3D, together with its details.

Discipline Rail
Discipline Rail has its geometry wholly modelled in 3D in case B. In case C, only if there were interfaces with another discipline, the object is modelled in 3D. In both cases, the details and installation diagrams are drawn in 2D in AutoCAD.

Discipline MEP(Mechanical, Electrical & Plumbing)
Discipline MEP becomes, depending on the case, part of other disciplines, see Table 9. The disciplines involved in all cases.. Hereby, the mechanical parts are often modelled in 3D. However in all cases the electrical and plumbing systems are only drawn in 2D. It is said that there is no budget to model the current situation of all electrical and plumbing systems in 3D. As infrastructure projects are over a vast area, there is a large amount of systems that have to be incorporated in the model. Therefore project teams prefer not to model it in 3D. This brings risks, as this information should be manually monitored by other disciplines, in order to prevent faults in their design.

Thus, it can be stated that disciplines Civil Engineering, Architecture and Mechanical are more familiar with modelling in 3D, including specifications. The disciplines Rail and Roads mainly model the geometry only. Except in case C, details were modelled in 3D for the Roads model. Details of discipline Rail are drawn in 2D. The Electrical and Plumbing systems are in all cases drawn in 2D.

Type of design change
As stated in the literature study, there are three types of design changes in BIM3D: geometry, position and specification. In all cases, change of specifications are in the minority. This implies that, such as stated in the interviews, details are often drawn in 2D. From all disciplines that used 3D modelling, the modellers said that the software used is user-friendly. However, the fact that details are often drawn in 2D due to time shortage implies that the families used in 3D modelling are not complete or limited. No details means that no further properties are filled in the description box of objects. This is important when taking off quantities from the BIM model, or when performing analyses. Furthermore, the information flow should be accurate, and it must be known by the project team where to find details of the design. Often, the details that are drawn in 2D by all disciplines end up on their own hard disk or shared drive within their own discipline. This means that other disciplines do not have access to details of a specific object, or even if they have access, they do not know where to find it. And if this object has an interface with one or more objects of another discipline, this may have negative consequences if not coordinated well.

BIM Usage (implementing design change)
When implementing multidisciplinary design changes, in case A and C, this is implemented simultaneously by each discipline by their own modellers after the coordination meetings. In case B, one discipline models the change in case of multidisciplinary design changes. Simultaneously implementing is more convenient, as each modeller is more familiar with their own discipline. Especially when modelling details in the 3D model, the knowledge or skills may lack within that discipline, and this will take more time than working together with more disciplines.

Some parts of the construction are being subcontracted. That means that some design changes are completely modelled by a subcontractor or partly. If the subcontractor works in 3D, the level of development of the models differs. In some cases only a 3D model with geometry is submitted, and in other cases this can be a 3D model with all specifications in it. If the contractor wants the data linked to the model, sometimes rework by the own project team is done to complete the model.

BIM Usage (as a tool)

In all three cases, BIM is mainly used as a design tool: during the design phase to detect clashes within the 3D model and to extract 2D drawings for work preparation and construction. This is mainly in the visualisation stage, as stated in literature. For the level of documentation, all information regarding the project should be embedded in BIM. To what extent BIM3D is used per case, can be found in Appendix F.

Relatics and the Document Management System(DMS) are both seen as part of BIM, as they contain information that can be linked to objects in the 3D model. The moment something changes on one side, the other information source does not change as well, as these are not live linked. Still, a parallel information flow may be applicable: human errors can then lead to incorrect information within one of the sources. As soon as live links are created between these databases, it can be called ''BIM''. The BIM4D model is modelled once for the critical parts of the project and not updated thereafter. This may be possible in case the team of work preparation has the knowledge of 4D, and the managers agree with implementing each change in 4D.

BIM usage (interfaces)

Managing interfaces differs per project. In case A and B, the disciplines that worked with Revit, could already see the interfaces 'live' as worksets are used and updated daily. The Roads model was also loaded as workset. Conversely, modellers of discipline Roads who worked with other software did not have this option and worked only with their own model. The interfaces with Roads were not always up-to-date, as the modellers had to release the model each time. This is also the case for Rail at case B.

To have an overview of interfaces and all objects, the disciplines and the rest of the project team consulted the coordination model in Navisworks. However, this is not preferred if a discipline wants to see interfaces because of a change, as no changes can be implemented in Navisworks and without live interfaces in own software, errors may arise during changing, which again take time to correct thereafter. It is stated that Navisworks is user-friendly to look into the coordination model. However, the project team has to be aware of the fact that information is missing and not up-to-date at the moment of access.

Automatic clash detection is consulted in each project. Clashes can only be detected in objects modelled in 3D. Logically, modellers should check interfaces manually with objects drawn in 2D. The frequency of clash sessions differs. Every two weeks is said to be too often(case B), at case A it was at most once per month, and at case C it is said that a total of 10 clash detection sessions was organised within 3 years. Clash detections should at least be performed before releasing each sub-model to work with, in the work preparation and execution. It is also essential that after clash detections, meetings are organised in which the modellers can discuss on how to solve the clashes together. During these sessions, also missing parts or gaps were found and solved.

4.4 Conclusion case studies

The case studies are analysed by both a qualitative as a quantitative study. In chapter 4.3, a cross-case analysis is given of the three analysed projects. This chapter gives the conclusion of the case studies in order to use as an input for the next chapter: procedure.

Concerning the organisational dimension, for each case, a different change process is set up, while this is unnecessary and thus inefficient. As mentioned in the change processes in Literature, also the change processes in these cases have not elaborated how the change has to be implemented. Impact analyses are seldom carried out, which increases the risk of adverse consequences on project constraints during the project. In both cases, without the change completely formalised, the change is implemented. In case B, no change proposal is shared before implementing. This increases the risk of cancelling changes by the client.
In order of often occurring causes of changes, these are Clients change requests, Partially incomplete documentation, Contractors change request, Change of regulations and Site-related changes. The amount of changes that are caused by client change requests implies that the client is not aware of possible consequences on the project, as only cost consequences and impact on delivery date of project are mentioned in the change forms.

Ideally, no changes are implemented, so the process is not disturbed. However, this is not feasible in practice. Still, an effort can be made to minimise the amount of design changes. This can be achieved by the project team. First of all, if changes can be rejected according to the UAV-gc, this has to be done. Furthermore, as clients change request was the highest cause of change in all cases, the client has to be made aware of the possible consequences of the change. So, the client requests less changes due to new wishes. For achieving this, potential risk, time and cost effects on design and construction have to be indicated clearly in the change form. These effects have to be measured by performing impact analyses.

Furthermore, it is not documented how long it takes to implement a change in the design. Therefore, planners experience still difficulty with estimating how long a design task takes. Construction activities are easier to plan. From now on, while implementing each change, it has to be registered, when working on the change is started with the number of people working on it. This is important, as in documenting how long it took to implement the change and for better planning of future changes.

In terms of technical dimension: project team members who have not worked with BIM are not aware of the value of BIM. On the other hand, BIM modellers and managers are well informed about the importance of BIM, regarding integrating databases and information. Most interviewees were positive about learning more and eventually work with BIM. There are databases, such as Relatics and Document Management System(DMS) that are declared as BIM, while there are no live links. BIM is used as an design-tool, while BIM has many opportunities to use it as an information tool. At the moment, some disciplines use BIM3D to design their work package. However, often, details are missing in the model, as sometimes the decision is made to draw some object or detail in 2D. In some cases, no interfaces are visible while designing, which is not preferable. And as there are no live links between databases, there may exist a parallel information flow in time, which ensures less efficiency in the design process. Thus, links have to be created between these databases. As soon as the three used databases: Relatics, BIM model and ThinkProject(DMS) are live linked, all databases together can be considered as BIM.

05

Procedure

This chapter gives an elaboration of the procedure that ensures effective implementation of design changes with the use of BIM, during the execution phase of infrastructural projects. With this, it is explained which insights from the literature study and case studies have led to this procedure. Experts have assessed this procedure to validate it. The suggested changes and whether they are implemented or not are summarised. Furthermore, it is explained how the project information should be structured for the use of this procedure.

This chapter answers the following sub-research questions:

5. How can a design change be implemented with the use of BIM?
6. How should the project information be structured for the use of BIM-based design change management?

5.1 Setting up of Procedure

The procedure is set up, based on the insights gained from the literature study and case studies. During the case studies, the design and construction process is comprehended by analysing the processes of BAM Infra. This is also used to design the procedure. This procedure focuses on minimising the number of changes and implementing changes efficiently.

A change procedure roughly consists of two parts: assessment of the change and implementing the change. In Figure 18, the change process is defined, as can be found in literature and at the contractor. In both cases, it is not defined how the change is implemented. If following the project life cycle, the implementation of the change can be outlined in design, work preparation and construction on-site, see Figure 19.

The case studies showed that each project drafts its procedure to implement design changes, and none of these are complete nor have BIM implemented. This means that an integrated procedure is required. For this, the change process, as shown in Figure 19, is translated into BIM terms. For this LOD(Level of Development) is used.
LOD indicates the level of development of an object, a sub-model or a complete model and consists of the following levels(BIMForum, 2019):

LOD100: Generic representation of object;
LOD200: Approximate geometry of object with size, shape and position;
LOD300: Includes geometry of object with size, shape, position and quantities;
LOD350: Includes geometry of object with size, shape, position, quantities and interfaces;
LOD400: Includes geometry of object with size, shape, position, quantities and details for fabrication;
LOD500: as-built information.

After the change is agreed on: the change is designed, as shown in Figure 19. If translating this to BIM, then design and work-preparation are working parallel. As soon as all geometry, including materials are indicated, LOD300 is reached. Hereafter, work preparation finds out, e.g. how the interfaces are constructed as input for LOD350 and what specifications and details for fabrication belong to the object via suppliers for LOD400. During work preparation also time and costs are updated. Then, the design is modelled up to LOD400, as it is clear how the objects are going to be constructed on-site, see Figure 20. The steps in the procedure are connected to three databases, that make together part of BIM.

Figure 18. The change process in literature and at BAM Infra

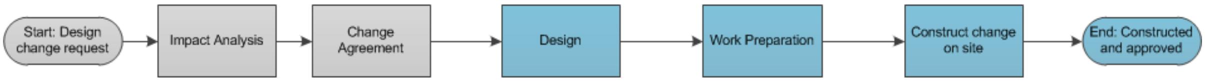


Figure 19. The change process following the project lifecycle.

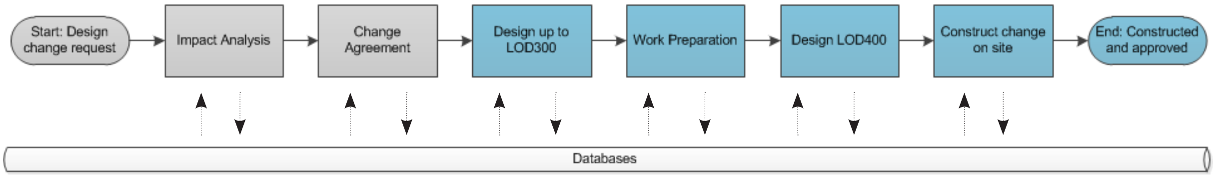


Figure 20. The change process translated to BIM.

5.2 Validation of Procedure

A procedure is drafted, see Appendix G, to be validated by an expert assessment to determine whether the procedure is applicable within BAM Infra. For this validation, the flowchart is divided into parts: A – I. During this session, first, a general overview of the flowchart is presented. Afterwards, each part is presented in detail, and the participants had to go through all the specifications of that part, which was shown on the hardcopy. After studying the concerned part, the participants had to individually indicate in an Excel table, whether they accepted that part. And if not, what changes are suggested. After each part is assessed, a discussion is started to understand the argumentation of the comments, in case these were unclear.

The group consisted of 7 experts. Design leaders of disciplines Civil Engineering, Roads, Rail and MEP took part in the session. Furthermore, two contract managers were present. As no BIM manager was present, the following day, a validation session is organised with a BIM manager, to guarantee the applicability of the procedure for the BIM part. Also then, the procedure was presented by the researcher, and an Excel had to be filled out by the BIM manager.

All comments of participants are gathered together, and analysed. In Appendix H, an overview is given of the suggested changes, which are implemented in the improved procedure. Also, an overview is given on changes that are recommended, however, not implemented.

Summarised, the most significant changes to the procedure are as follows:

- Impact analysis has to be carried out for all changes, and if the client is responsible for the change, the impact analysis should be financed by the latter. If no agreement is reached about the impact analysis, the change is rejected.
- Project team approval and client approval are added to LOD300 design and LOD400 design. Project team gives approval based on verifications done in Relatics. The client validates the design by looking in the BIM model.
- Also, clash detection is added to LOD300 design.

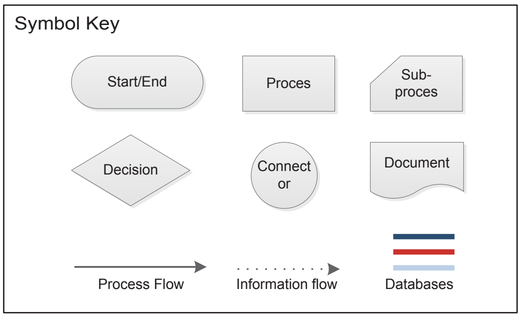
5.3 Final Procedure

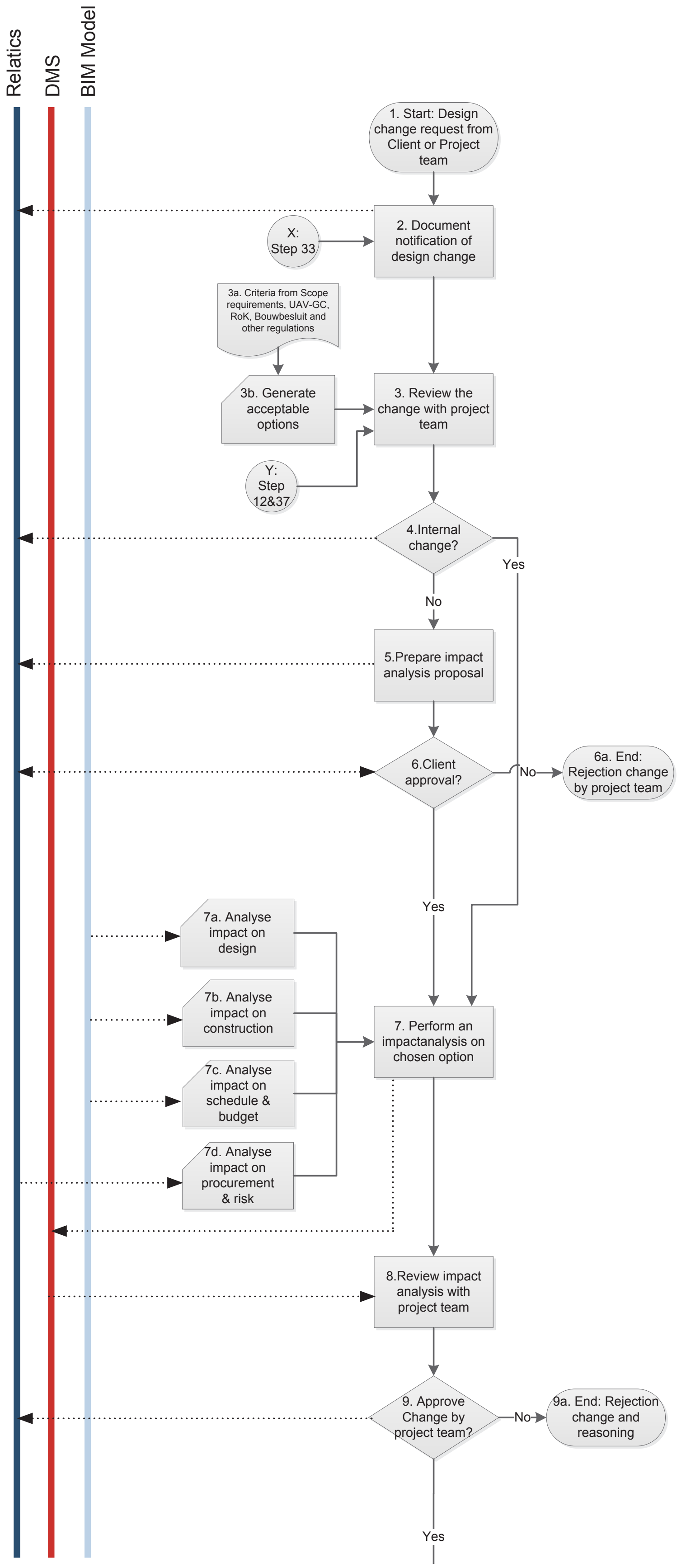
In the final procedure, see Figure 21, most suggested changes are implemented, as shown in section 5.2. Furthermore, own optimisations are added to improve the procedure. These are mainly in the design of the procedure: All databases are placed to the left side as lines that run through all three pages, so it is not suggested that there are more than 3 databases in this procedure. The database Thinkproject is a Document Management System(DMS). As not in all projects, ThinkProject is used as a DMS database; the name DMS is used in the procedure. Also, links are added to decisions, and missing information links are added. Furthermore, specifications are extended and designed more clear.

*Figure 21.**Procedure** “Implementing design changes with use of BIM”*

This procedure is to be used by the project team in case of a change request from the client or the project team. In the specifications is stated which information should be transferred into a database and by whom. Following the steps will ensure an effective implementation of design change.

There are three databases used in this process.
The BIM model, which includes 3D, 4D and 5D; Relatics; DMS(Document Management System).





1.Start: Design Change request from Client or Project Team.
The client or member of the project team notifies the contract manager in case of a change request.

2. Document Notification of design change in Relatics.
The contract manager documents in Relatics: the date of request, the cause of change, the scope of change and the concerned disciplines.

- X: *If in step 33, a deviation is found.*

3. Review the change with The project team.
First options are generated(3b) based on the requested change and criteria(3a). These are the scope requirements, UAV-GC, RoK, Bouwbesluit and other regulations. Then a meeting is initiated with the project team in which an acceptable option is chosen, based on time, budget and risks. It is also determined whether the change is internal or needs client approval. The actors involved at this step are the contract manager, construction manager, concerned design leaders and in case of a multidisciplinary change the design manager.

- Y: *If in step 12a, the client wants other options to be investigated. Or if in step 37 the change is not approved after construction.*

4. Internal Change?
--> The contract manager documents in Relatics whether the change is internal or not. If the change does not need client approval, the impact analysis can be performed > Step 7.

5. Prepare impact analysis proposal
The contract manager uploads the proposal in Relatics.
In this proposal, it is stated what the scope is of the impact analysis and how much time and budget is needed to perform it.

6. Client approval?
If the client does not agree with the impact analysis, the change is rejected by the project team(6a).
-- > The client approves through Relatics.

7. Perform an impact analysis
During this step, an impact analysis is performed. Hereby, the impact on design effort is determined by the concerned design leaders and design manager. It is also determined in which stage the design is, that is concerned with the possible change(7a). The impact on construction work is determined by the construction manager(7b). The Planner/BIM 4D modeller determines the impact on the schedule. The costs are determined by the Cost engineer/ BIM5D modeller(7c) and the risks by the risk manager(7d). Whether suppliers are available is determined by the procurers(7d). Furthermore, all relevant documents that are stated in the contract are taken into account.

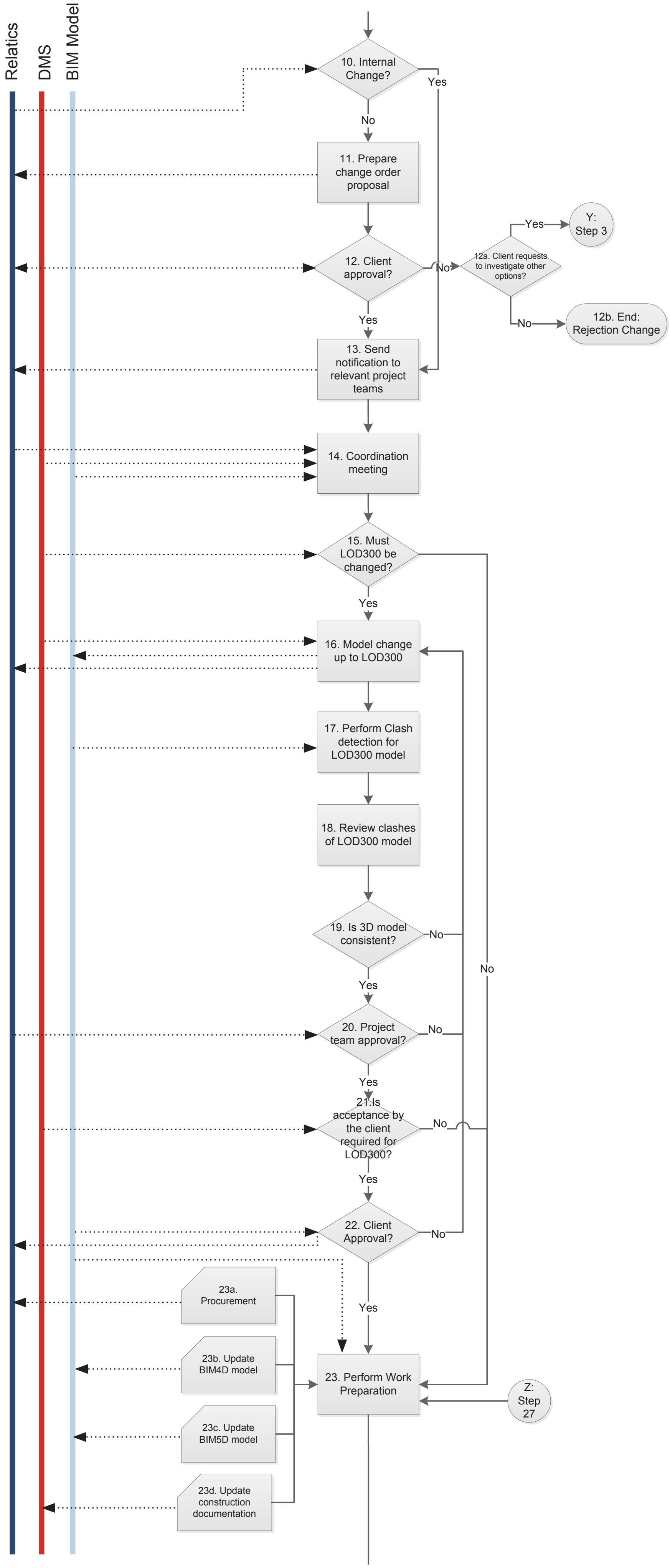
--> To analyse the impact on design, the BIM3D model is looked into. To analyse the impact on construction and schedule the BIM4D model is consulted. For budget: the BIM5D model. And for the current suppliers and risks, Relatics is consulted.

--> The results of the impact analysis are included in a document, which is uploaded to DMS.

8. Review impact analysis with project team
The construction manager, contract manager, project manager, design manager and design leaders are involved in this review session. Whether the risks and costs are acceptable are decided by the project manager. Furthermore, the amount of suppliers and the technical feasibility of the chosen option is looked into.

--> During this review session, the impact analysis document from DMS is used.

9. Approve change by project team?
If the change has an unacceptable impact on the project constraints, then the change may be rejected based on conditions stated in UAV-gc(9a).
--> The decision is registered in Relatics, together with reasoning by the contract manager. If it is not an internal change, the client is updated through Relatics.



10. Internal Change?
If approved by the contract manager in Relatics and it is an internal change, then the change can be notified to relevant departments> step 13.

11. Prepare change order proposal
The amount of time needed to implement the change has to be included in this proposal, and the possible risks and consequences of the change has to be stated clearly. So the client is aware of possible consequences.
--> The contract manager drafts a change order proposal and uploads this to Relatics. In this proposal: cause and scope of change, time, cost effects and risks have to be included.

12. Client approval
--> The client approves through Relatics. After approval, the possible risks and changed scope requirements are automatically set to current status. If the client does not give approval(12a), and does not want the project team to investigate other options, the change process will end(12b).

- Y: *If the client requests to investigate other options, then stated in the proposal, the project team will review the change by generating other possible options>step 3.*

13. Send notification in Relatics
If the client approves, or in case of internal changes, the design change can be notified to project members.
--> All relevant disciplines that were already entered in step 2 of this process are notified through Relatics by a pop-up alert. The contract manager sends this notification. In this pop-up alert it is described what the change is and which work package it concerns.

14. Coordination meeting
In this meeting, relevant project members of Design team, Work preparation and Construction team who are notified through Relatics are present. How the change will be implemented is discussed.
--> During this meeting, the BIM model and all relevant information from DMS and Relatics is used.

15. Must LOD300 be changed?
-- > See impact analysis results in DMS. If the change concerns a LOD400 model, the project team can proceed with work preparation.

16. Model Change up to LOD300
--> The design team will model the change up to LOD300 in BIM3D according to the BIM Plan(from DMS). In a BIM app the design team has to register: The start date of implementing the change in the design and the number of modellers working on the change.
--> Requirements are verified in Relatics.
*If drawing in 2D, the link (to DMS) of the 2D detail has to be placed in the properties box of relevant object(in BIM3D).

17. Perform Clash detection for LOD300 model
This step is even more important if no interfaces are visible in software of each discipline and in case of multidisciplinary design changes.
--> An automatic detection in 3D is performed on all sub-models and the clashes can be seen in the BIM model.

18. Review clashes of LOD300 model
The clashes are discussed in an initiated meeting with the design team and Work preparation.

19. Is 3D model consistent?
If there are inconsistencies in 3D in and between the sub-models, then the design team should solve this problem > step 16.

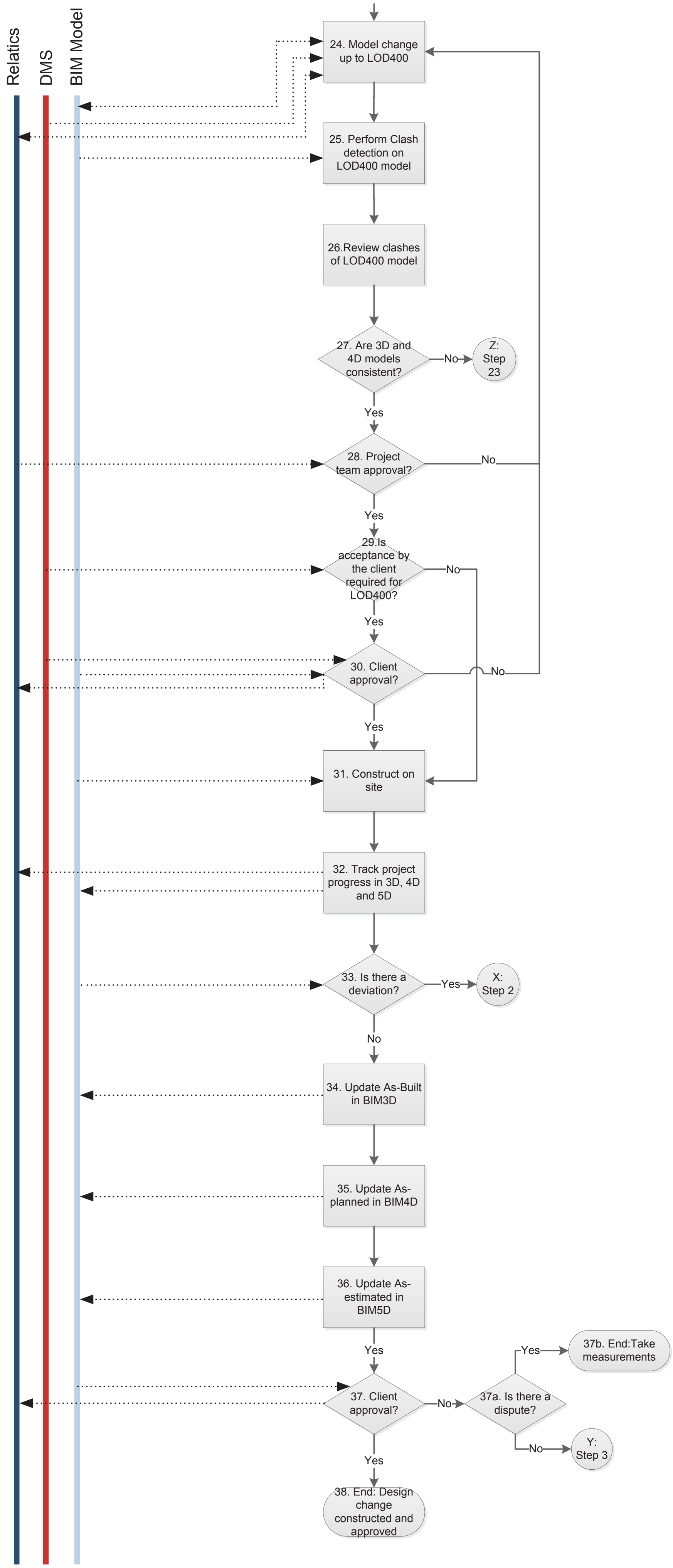
20. Project team approval?
Is the design according to the scope requirements? Can all requirements be verified?
--> If all requirements are verified in Relatics, design team can proceed.

21.Is acceptance by the client required for LOD300?
It is stated in the contract whether the LOD300 design should be accepted by the client before proceeding.
-- > This is checked in DMS by the design team.

22. Client Approval?
If the client does not accept the LOD300 model, the design should be changed.
--> The Client views the design in BIM, and approves through Relatics per work package.

23. Perform Work Preparation
During this stage of the process, the work preparation team will purchase materials needed and look possibly for any sub-contractors or suppliers. Also, the effects in time and costs are modelled in BIM and construction documentation is updated.
--> Procurement registers details of suppliers in Relatics(23a);
--> BIM4D and BIM5D modellers update their model(23b, 23c);
--> Construction documentation is updated in DMS by the work preparation team(23d).

- Z: If there are inconsistencies in the 3D and 4D model.



24. Model change up to LOD400
The change can be together with the input from work preparation be further modelled up to LOD400.
--> Information is gathered from Relatics for the supplier details (e.g. specifications of objects that are determined by manufacturers).
--> Information is gathered from the BIM Model, for time and costs.
--> Information is gathered from the DMS, for the construction plans.
--> The objects are modelled by the design team in BIM3D based on the BIM Plan. *If drawing in 2D, the link (to DMS) of the 2D detail has to be placed in the properties box of relevant object.
--> Requirements are verified in Relatics.

25. Perform clash detection
This step is even more important if no interfaces are visible in software of each discipline and in case of multidisciplinary design changes.
--> An automatic detection in 3D and 4D is performed on all sub-models and the clashes can be seen in the BIM model.

26. Review clashes with project team
The clashes are discussed in an initiated meeting with the design team and Work preparation.

27. Are 3D and 4D model consistent?
- Z: *If there are inconsistencies in 3D and 4D between the sub-models, then the design team should solve this problem. Also Work Preparation, may have to solve clashes in their models> step 23.*

28. Project team approval?
Is the design according the scope requirements? Can all requirements be verified?
--> If all requirements are verified in Relatics, design team can proceed.

29. Is acceptance by the client required for LOD400?
It is stated in the contract whether the LOD300 design should be accepted by the client before proceeding.
-- > This is checked in DMS by the design team.

30. Client approval?
If the client does not accept the LOD400 model, the design should be changed.
--> The Client views the design in BIM, views the construction documentation in DMS and approves through Relatics per workpackage.

31. Construct on site
--> As soon as the LOD400 model is agreed on, the site manager is notified by the BIM app, so the BIM model can be used on site.

32. Track project progress in 3D, 4D, 5D
For tracking the project progress, information is gathered and reported in the BIM app and in Relatics by the site manager:
--> Relatics (link with BIM3D): The quality of built objects (inspection).
--> BIM4D: Expected end date of workpackage, Actual start date of workpackage, Actual end date of workpackage.
--> BIM5D: The used quantities of material, The amount of manhour, Equipment use.

Inspection reports are filled in Relatics. However, due to the live link with the BIM model, the progress updates can also be seen in the properties box of each object in the 3D model. Information gathered for BIM4D and BIM5D are directly put in the BIM model.

33. Is there a deviation?
- X: *If during construction, deviations are observed, then these have to be documented by the contract manager and reviewed by the project team > step 2.*

34. Update as-Built in BIM3D
After construction and approval, as-Built is modelled in BIM3D. Hereby, LOD's of objects are updated and objects within the model are changed if necessary.

35. Update as-Planned in BIM4D
This is an important task as it gives insight in whether the determined planning was accurate and will give input for future planning of similar activities.
--> The BIM4D modeller checks and approves the data filled in by the site manager in the BIM app.

36. Update as-estimated in BIM5D
This is an important task as it documents whether the determined costs of the change are accurate and will give input for future estimating of similar activities.
--> The BIM5D modeller checks and approves the data filled in by the site manager in the BIM app.

37. Client approval?
The client is asked for approval of the constructed change. If the client gives no approval and there is a dispute(37a), measurements have to be taken(37b) and court proceedings can be initiated if no agreement can be reached.
--> Client approves through Relatics.
- Y: *If the clients gives no approval and there is no dispute > step 3.*

38. End: Design change constructed and approved
If the client approves, the design change process ends.

5.4 Information structure of the project

For using the given procedure, the project information needs to be structured differently. In literature, one of the mentioned design changes due to project-related causes is the poor communication of information between parties and within the project team. Hereby, it has to be considered that project teams in construction projects are temporary in nature; this means that information may disappear over time. Currently, information is mainly gathered through e-mails and during meetings. This has to change: All information regarding the projects, has to be stored in and shared through databases. In this procedure, for all steps, it is indicated which data should be shared by whom through which databases. It must be clear to all project members that all information that is gathered or produced has to be available for the whole team. This ensures more efficiency and thus less time and cost overrun.

In Figure 22, it is shown in which step of the procedure what input or output is gathered from the databases.

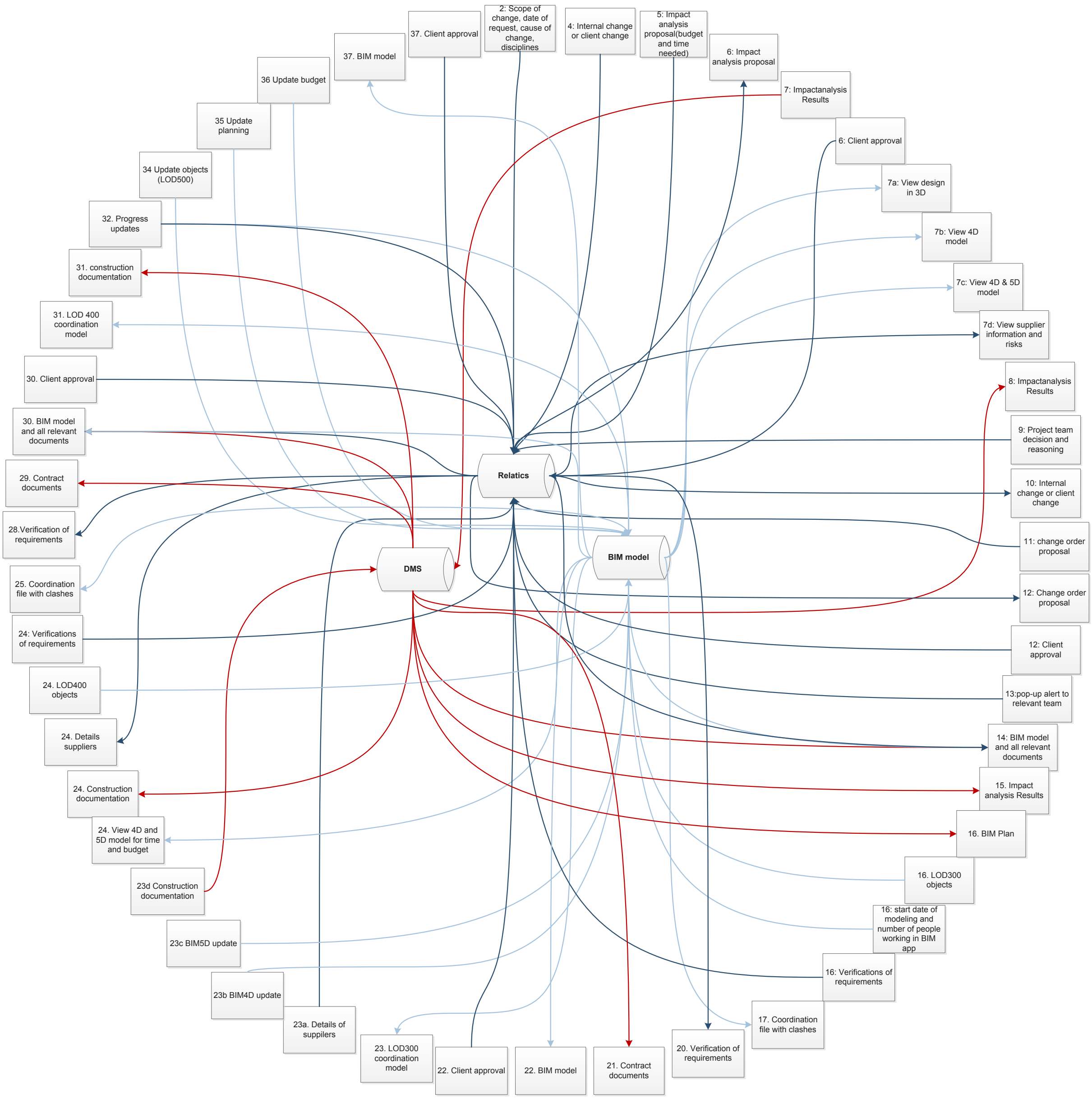


Figure 22. Information structure of project

06

Discussion

In the previous chapter, a procedure is set up for implementing design changes during the execution phase of infrastructural projects. Hereby BIM is used in the procedure. This chapter focuses on giving recommendations for BIM3D use, how this procedure can be introduced in the company and at the client. Furthermore, it is discussed how the procedure can be maintained over time, how the necessary culture change can be realised, and the applicability of the procedure.

6.1 Recommendations for BIM3D use

In the last chapter, the final procedure and the corresponding information structure of the project is thoroughly described. To make the most of this procedure and to ultimately reach level 2 documentation, recommendations are presented in this section for BIM3D use.

First of all, the BIM goals of a project have to be drafted into a BIM Plan. In the plan, it should be documented how BIM is used and for which purposes, which software is used by which discipline, how this information has to be stored and shared and which Level of Development the sub-models have to be modelled in which stage of the project. Insight into all interfaces is valuable during designing. For this matter, worksets can be used by all disciplines. In this manner, most interfaces are designed correctly, and not much effort is needed to correct these when discovered by the clash detections.

Next to insight in interfaces, disciplines need to model different objects. To save time, when modelling, it is recommended to make use of an object library. This library can be set up by the company, with assistance from suppliers. If there are a large number of objects available, there is no need to draw details in 2D, due to shortage of time. Preferably, modellers work with parametrised objects. This way, when changing the geometry of an object, the specifications are changed simultaneously. In case the modeller wants to go back to an earlier modelled option, this is then also possible.

If during the transition phase 2D is used, a link to DMS should be placed of the 2D detail in the properties box of concerned object in BIM3D. This way, no information is missing, and all disciplines have access to all design information. Also in case of a design change, related 3D objects and 2D documents are immediately visible.

Last, it is also recommended to make use of an automatic LOD detection. This means that when modellers register an object as LOD400, no further changes can be made to the object, as it is being constructed on-site. If the modeller wants to change a component, then reasoning is needed. After approval of the BIM Manager, the modeller can change the object. This method prevents changes to objects that are frozen and ensures more advantages with automatisation, see next section.

6.2 Introduction of the procedure in the company

A procedure has been set up, and now must be introduced in the company. At the moment, there are several stand-alone processes in the business processes of the company. With adopting this procedure, the current change processes for both ‘’Clients change request’’ and ‘Contractors change request’’ shall no longer apply. The procedure gives a general overview of the steps that have to be taken and information that has to be shared. All detailed processes related to this procedure must be linked to databases. However, during the adoption phase, the available processes can be used if more detail is needed in order to perform a step. This applies for e.g. the steps: Project team approval(Verification processes) and Clash detection.

As BIM is used mainly on a visualisation level and partly on documentation, a cultural transformation is required to bring it to the next level: analysis in BIM. For this, a business strategy needs to be formed by the management team of BAM Infra. For a correct implementation of BIM technology, the emphasis of the business strategy should be on the value of information exchange within business processes instead of the result: the model(Smith & Tardif, 2009). With this, the implementation of BIM processes, the developed procedure and associated objectives in the company should be supported.

Specific barriers may occur during adoption of BIM, as socio-organisational, financial, contractual, technical and legal barriers(Alreshidi, Mourshed, & Rezgui, 2017). These can be largely overcome with the right business strategy. This strategy will require financial resources, education, training and an adoption period, which may drop the productivity of staff temporarily. The contractor should be aware that full adoption of BIM will ensure competitive advantages and financial benefits in the long term. That is why the organisation should continuously strive to develop in terms of BIM and act in accordance with it(Smith & Tardif, 2009).

In organisational terms of the procedure: The management team and project teams should realise that changes bring process disturbance and other negative consequences. This means that management must put forward the idea that no profit can be earned from changes and that the number of changes must be minimised, to save both time and money. Thus, changes must be rejected if possible, also if the own project team requests the change. However, this also means that during the Tender phase, projects should not be accepted if a high number of changes are expected.

This procedure will be part of the business processes that have incorporated BIM. With support from the management team, more financial resources should be made available for correctly implementing this procedure. First, ICT department has to design the links between the three databases. Simultaneously, education and training have to be provided. As each employee, each year, has to take courses, the following training each employee has to take, must be a BIM-related course. In these courses, the emphasis must be on the information side of BIM, and less on modelling of geometry. Hereby among others, an in-depth understanding of new business processes related to BIM should be gained and an understanding of how BIM can make the project more coordinated(Hardin & McCool, 2015). After following this course, it should be possible for all employees to follow BIM courses with emphasis on modelling. For the design and work preparation team, the latter is also mandatory.

As regards to the procedure, it is recommended to implement this only in new projects as it can be challenging to implement a new procedure in an ongoing project. At the start of each project, the whole project team has to follow a training based on this procedure. Each year of the project, this has to be repeated. The procedure has to be maintained by the process manager. Each year, it should be reviewed to find out if the procedure is still up-to-date regarding technological developments regarding BIM.

Hereby, in the case of automation, most steps will take less time. For example, the impact analysis: if more historical data is registered, the analysis can be performed much more accurately and in less time. The historical data is then categorised on object type and activity, regarding to time, budget and risks. Other steps that can be automated in coming years are, e.g. registering progress in time. As soon as the LOD detection is linked to the planning in 4D, the planning is automatically updated each time the modeller assigns an increased LOD to an object. This means that better insight is gained into project progress. In the case of computerisation of LOD detection: the modelling software continuously recognises and registers the Level of Development of each object. In this way, no objects are forgotten to log LOD, and project progress is available for the whole design. With historical data, even reliable forecasts can be delivered for the amount of time needed for a specific task. The more the BIM process is automated, the more advantages BIM provides for design change management.

Except for automation, the recommendations have to be followed to implement this procedure. The contractor has the knowledge, and it is possible to follow through with these recommendations. As soon as the procedure is implemented, the design change process will become more efficient.

6.3 Introduction of the procedure at the client

In the last section, it is highlighted why and how the project team needs a culture change and how the procedure can be implemented in the company. However, not only the project team, but also the client has to realise a culture change. Currently, the client asks for 2D drawings to review and often does not ask for an as-built model in BIM3D. This results in the contractor not wanting to invest time and budget in modelling an as-built version. The client should realize that an as-built model can be used for the maintenance phase of their project, and this has several benefits in comparison with using 2D drawings.

As many clients are working with this contractor, it is recommended to introduce this procedure during the Tender phase. With this, it has to be made clear by the contractor that this procedure is more transparent than current processes. The client should approve the design by looking into the BIM3D model. In this way, the client is kept up-to-date for the whole design and no 2D drawings have to be made only to be reviewed by the client.

6.4 Applicability of procedure

The procedure is created from a contractor's perspective and designed to be used by project teams of infrastructure projects that are based on a UAV-gc contract. Experts validated the applicability of the procedure within the contractor. However, as the standard design, work-preparation and construction processes are followed during the creation of this procedure, it is expected that it can be used for the whole infrastructure field in the Netherlands. This procedure may also be used among the broader AEC field if using UAV-gc contracts. If using another contract, the procedure should be revised.

07

Conclusions & Recommendations

In this research, the implementation of design changes during the execution phase of infrastructural projects, with the use of BIM, are analysed. In this chapter, the conclusions of the research are presented, its limitations are presented, and recommendations for further research are described.

7.1 Conclusions Research questions

How can design changes be implemented during the execution phase of infrastructural projects, with the use of BIM?

For the theoretical framework of this thesis, design change and BIM are studied in literature. It is identified that two types of design change occur during execution phase, whereby the design can still be in progress or finished on that part of work. Furthermore, it was identified that these changes are most often caused by client-initiated changes. Other frequent changes occur within project-related, design-related, contractor-related and external factors. The later the design change is requested and implemented, the higher the impact on project constraints. And the more changes, the higher the inefficiency of project teams. These changes can have a time and cost impact, which are interrelated. The costs are both direct and indirect. The latter is related to the inefficiency of the team members due to process disturbance and lost effort on work already done.

The implementation of changes are following specific change processes. In the literature study, a change process is described based on more sources. Due to the complexity of infrastructural projects, a substantial amount of information is processed and managed during these change processes. A good information flow has to be reached, so all departments are notified of the change and accompanying activities that have to be carried out. This can be achieved by using BIM, according to literature.

BIM is a process that generates a product in 3D, that can be extended to 4D(time) and 5D(costs). Hereby, BIM can be used to process all information of the infrastructural project. BIM has many benefits, such as design change management, better coordination of information and better project control. The two types of design change mentioned may lead to more types of changes in BIM3D, which can again lead to changes in time(4D) and costs(5D) or both. These types of changes are used in the case studies, to determine how often these occur and whether BIM is used by implementing the design changes.

To determine how a design change is implemented in practice and what the user experience is with BIM, case studies are used as a research method. Hereby, three infrastructural projects are both qualitatively and quantitively analysed on the organisational and the technical dimension. It is recognised that both change processes in literature and in practice are not complete and are not linked with databases as BIM. In practice, every project team changes the standard change process to their preferences: this is inefficient. In order of most occurring cases, these are Client change requests, Partially incomplete documentation, Contractors change request, Change of regulations and Site-related changes. The amount of changes that are caused by client change requests implies that the client is not aware of the possible consequences to the project, as only cost consequences and impact on delivery date of project are mentioned in the change forms. This cause and contractors change request can both be reduced in the case that both project team and client are aware of all consequences on design, construction, risks, time and budget. This is possible by carrying out impact analyses.

From the case studies, it also appeared that project team members that do not work with BIM, are not aware of the value of BIM: mainly clash detection is indicated when asking for the definition of BIM. On the other hand, BIM managers and BIM modellers are well informed about BIM, concerning the data integration and linkage of databases. Currently, within BAM Infra, BIM is used primarily for visualisation and partly for documentation purposes, thus level 1 and 2 of BIM usage. Concerning design changes, only 31% is wholly implemented in BIM3D. The databases BIM model, Relatics and Document Management System are all named as BIM. However, these are not linked to each other, which means that these may contain different information for one specific object. It is identified that the disciplines Civil Engineering, Architecture and Mechanical work most with BIM3D. The discipline Rail and Roads works mostly with geometry only, and Electrical & Plumbing systems only work in 2D. This means that a culture change is required, and mainly within the disciplines Rail, Roads and E&P.

Furthermore, it is identified that often details are missing in the BIM3D model, and interfaces are not always visible in the 3D model. These mentioned aspects reduce efficiency in the design process. For 4D usage it is only modelled once, for the critical parts of the work. BIM5D is not used in these cases. However, it is involved in other cases within BAM Infra.

To make use of design change management in BIM, and thus reach level 3(model-based analysis) and 4(integrated analysis) of BIM usage, a procedure is set up to make all steps clear from initiation of the change till construction and approval on site. The objective of this procedure is to make the change process more efficient. For this, information is used from the literature study and case studies. Primarily, it is most efficient for the project to minimise the amount of changes, as stated in literature and identified in the case studies. In order to reach this, changes are rejected in this procedure if the client does not agree with financing the impact analysis in the case of client-initiated changes and the changes are also rejected if the project team does not agree with the consequences of the change, based on condition stated in the UAV-gc. After minimising the number of changes, it was essential to make all steps clear to the project team that have to be taken. For this, during the case studies, the design and construction processes are comprehended. These are then connected so that an integrated procedure is created. Hereby, almost each step has an input or output to one or more databases within BIM. This ensures that all information produced is stored.

Following this procedure ensures a higher efficiency for the project team. Next to this procedure, also a schematic overview is given on how the project information has to be structured. It is essential to realise that project teams of construction projects are temporary. That means that information shared through e-mail or in meetings disappear in time. In order to prevent this, all information should be gathered together in BIM. For the design change procedure given, the structure is explained by displaying all data that has to form an input or output from one or more databases for each appropriate step in a scheme. In conclusion, one of the most significant advantages of BIM is design change management, and this research has provided a procedure to benefit from this advantage.

7.2 Limitations of Research

Although this research presented a more efficient way to implement design changes with the use of BIM, there are still some limitations. These are as following:
- The procedure is not tested due to the limited time of conducting this research. However, a validation session is organised to ensure the applicability of the procedure within the contracting company and design consultant: BAM and BAM Infraconsult.
- This procedure is created from the perspective of two main contractors. The case studies consisted of projects of BAM and one other partner firm. This means that the procedure might be biased and not compatible for all contractors.
- A procedure is created to ensure more efficient change processes; however, this is not measured in terms of time and costs.

- A procedure is given, however, how this will be implemented into projects and within the organisation is not thoroughly elaborated on.

7.3 Recommendations for further research

Due to time constraints, the procedure could not be tested in practice. Further research can be done by testing this procedure in practice in projects within the infrastructure field with cooperation of different type of contractors. Follow-up research can be done for application within the broader AEC sector. Hereby, also different contract types can be taken into account, as DBFM. Furthermore, recommendations are given for implementing this procedure. However, this requires another study to describe thoroughly how organisational change can be used to implement this procedure. As mentioned in the discussion, there are possibilities to computerise the steps involved. Further research can be performed on how this procedure can become even more efficient by automating it and taking it to the highest level of BIM usage: 5. Automation and optimisation.

08

List of References

Alreshidi, E., Mourshed, M., & Rezgui, Y. (2017). Factors for effective BIM governance. Journal of Building Engineering, 10(February), 89–101. https://doi.org/10.1016/j.jobe.2017.02.006

Auditor General of Western Australia. (2012). Major Capital Projects (Vol. 12). Perth. Retrieved from https://audit.wa.gov.au/wp-content/uploads/2013/05/report2012_121.pdf

Autodesk Inc. (2002). Building Information Modelling. Autodesk. USA: San Rafael.

BIMForum. (2019). Level of Development (LOD) Specification Part I & Commentary. Retrieved from www.bimforum.org/lod

Bouw Informatie Raad. (2011). Objectenbibliotheken in de bouw. Retrieved from http://www.nijssen-management-advies.nl/cms/images/downloads/09-10-21 objectenbibliotheken in de bouw v4.pdf

Bower, D. (2000). A systematic approach to the evaluation of indirect costs of contract variations. Construction Management and Economics, 18(3), 263–268. https://doi.org/10.1080/014461900370636

Chan, D. W., & Kumaraswamy, M. M. (1997). A comparative study of causes of time overruns in Hong Kong construction projects. International Journal of Project Management, 15(1), 55–63. https://doi.org/10.1016/S0263-7863(96)00039-7

Chang, A. S. T., Shih, J. S., & Choo, Y. S. (2011). Reasons and costs for design change during production. Journal of Engineering Design, 22(4), 275–289. https://doi.org/10.1080/09544820903425218

Cheng, J. C., Lu, Q., & Deng, Y. (2016). Analytical review and evaluation of civil information modeling. Automation in Construction, 67, 31–47. https://doi.org/10.1016/j.autcon.2016.02.006
CIFE. (2015). VDC and BIM Scorecard. Retrieved from https://vdcscorecard.stanford.edu/technology-area-insights

CII. (2011). CII Best Practices Guide: Improving Project Performance. Implementation Resource 166-3 (3rd ed.). Austin: The University of Texas.

CROW. (2005). UAV-GC 2005: Model basisovereenkomst en toelichting.

Czmoch, I., & Pękala, A. (2014). Traditional design versus BIM based design. Procedia Engineering, 91, 210–215. https://doi.org/10.1016/j.proeng.2014.12.048

Dvir, D., & Lechler, T. (2004). Plans are nothing, changing plans is everything: The impact of changes on project success. Research Policy, 33, 1–15. https://doi.org/10.1016/j.respol.2003.04.001

Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2011). BIM Handbook. A guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors. (2nd ed.). Hoboken, New Jersey: John Wiley & Sons, Inc.

Flyvbjerg, B., Garbuio, M., & Lovallo, D. (2009). Delusion and Deception in Large Infrastructure Projects: Two models for explaining and preventing executive disaster. California Management Review, 51(2), 170–194.

Grilo, A., & Jardim-Goncalves, R. (2009). Value proposition on interoperability of BIM and collaborative working environments. Automation in Construction, 19, 522–530. https://doi.org/10.1016/j.autcon.2009.11.003

Hameed, A., Rahman, I. A., Faris, M., & Hasan, A. (2014). Significant Causes and Effects of Variation Orders in Construction Projects. Research Journal of Applied Sciences, Engineering and Technology, 7(21), 4494–4502. https://doi.org/10.19026/rjaset.7.826

Hanna, A. S., Russell, J. S., & Vandenberg, P. J. (1999). The impact of change orders on mechanical construction labour efficiency. Construction Management & Economics, 17(6), 721–730. https://doi.org/10.1080/014461999371060

Hao, Q. ;, Shen, W. ;, & Neelamkavil, J. (2008). Managing Changes in Construction. https://doi.org/10.4224/20378329

Hardin, B., & McCool, D. (2015). BIM and Construction Management: Proven tools, methods and workflows (2nd ed.). John Wiley & Sons, Inc. https://doi.org/.1037//0033-2909.I26.1.78

Haydl, H. M., & Nikiel, A. W. (2000). Design and Construction Errors - Case Studies. Practice Periodical on Structural Design and Construction, 5(3), 126–130. Retrieved from https://ascelibrary.org/doi/pdf/10.1061/%28ASCE%291084-0680%282000%295%3A3%28126%29

Hsieh, T. Y., Lu, S. T., & Wu, C. H. (2004). Statistical analysis of causes for change orders in metropolitan public works. International Journal of Project Management, 22(8), 679–686. https://doi.org/10.1016/j.ijproman.2004.03.005

Hwang, B. G., & Low, L. K. (2012). Construction project change management in Singapore: Status, importance and impact. International Journal of Project Management. https://doi.org/10.1016/j.ijproman.2011.11.001

Ibbs, C. W., Wong, C. K., & Kwak, Y. H. (2001). Project Change Management System. Journal of Management in Engineering, 17(July), 159–165. https://doi.org/10.1061/(ASCE)0742-597X(2001)17:3(159)

Juszczyk, M., Tomana, A., & Bartoszek, M. (2016). Current Issues of BIM-based Design Change Management, Analysis and Visualization. In Procedia Engineering (pp. 518–525). https://doi.org/10.1016/j.proeng.2016.11.653

Keane, P., Sertyesilisik, B., & Ross, A. D. (2010). Variations and Change Orders on Construction Projects. J. Leg. Aff. Dispute Resolut. Eng. Constr (Vol. 2). Retrieved from https://ascelibrary-org.tudelft.idm.oclc.org/doi/pdf/10.1061/%28ASCE%29LA.1943-4170.0000016

Koch, J. E., Gransberg, D. D., & Molenaar, K. R. (2001). Design-Build Change Orders. In Project Administration for Design-Build Contract - A Primer for Owners, Engineers, and Contractors (pp. 191–218). American Society of Civil Engineers (ASCE).

Liu, F., Jallow, A. K., Anumba, C. J., & Wu, D. (2014). A Framework for Integrating Change Management with Building Information Modeling. In International Conference on Computing in Civil and Building Engineering. https://doi.org/https://doi.org/10.1061/9780784413616.055

Mejlaender-Larsen, Ø. (2015). Using a change control system and BIM to manage change requests in design. In 32nd CIB W78 Conference (pp. 549–558). https://doi.org/10.1080/17452007.2016.1220360

Motawa, I. A., Anumba, C. J., Lee, S., & Peña-Mora, F. (2007). An integrated system for change management in construction. Automation in Construction, 16, 368–377. https://doi.org/10.1016/j.autcon.2006.07.005

Nahod, M. (2012). Scope Control Through Managing Changes in Construction Projects. Organization, Technology & Management in Construction: An International Journal, 4(1), 438–447. https://doi.org/10.5592

Paik, S., Leviakangas, P., Morrison, D., Naas, L., & Wang, X. (n.d.). Building Information Modelling in Change Management: A Case Study, 438–445.

Pilehchianlangroodi, B. (2012). Change Management with Building Information Modeling: A Case Study. The University of British Columbia. https://doi.org/10.14288/1.0050914

Rokooei, S. (2015). Building Information Modeling in Project Management: Necessities, Challenges and Outcomes. Procedia - Social and Behavioral Sciences, 210, 87–95. https://doi.org/10.1016/j.sbspro.2015.11.332

Shourangiz, E., Mohamad, M., Hassanabadi, M., Banihashemi, S., Bakhtiari, M., & Torabi, M. (2011). Flexibility of BIM towards Design Change. In Proceedings of 2nd International Conference on Construction and Project Management (pp. 79–83).

Sigalov, K., & König, M. (2017). Recognition of process patterns for BIM-based construction schedules. Advanced Engineering Informatics, 33, 456–472. https://doi.org/10.1016/j.aei.2016.12.003

Smith, D. K., & Tardif, M. (2009). Building Information Modeling - A strategic Implementation guide for architects, engineers, constructors, and real estate asset managers. https://doi.org/.1037//0033-2909.I26.1.78

Stasis, A., Whyte, J., & Dentten, R. (2013). A Critical Examination of Change Control Processes. Procedia CIRP, 11, 177–182. https://doi.org/10.1016/j.procir.2013.07.053

Sun, M., Fleming, A., Senaratne, S., Motawa, I., & Yeoh, M. L. (2006). A change management toolkit for construction projects. Architectural Engineering and Design Management, 2(4), 261–271. https://doi.org/10.1080/17452007.2006.9684621

Sun, M., Sexton, M., Aouad, G., Fleming, A., Senaratne, S., Anumba, C., … Yeoh, M. (2004). Industrial Report: Managing Changes in Construction Projects. Engineering and Physical Science Research Council (EPSRC).

Sun, Ming, & Meng, X. (2009). Taxonomy for change causes and effects in construction projects. International Journal of Project Management, 27. https://doi.org/10.1016/j.ijproman.2008.10.005

Turk, Z. (2016). Ten questions concerning building information modelling. Building and Environment, 107, 274–284. https://doi.org/10.1016/j.buildenv.2016.08.001

Verschuren, P., & Doorewaard, H. (2010). Designing a Research Project (2nd ed.). The Hague: Eleven International Publishing.

Wu, C. H., Hsieh, T. Y., Cheng, W. L., & Lu, S. T. (2004). Grey relation analysis of causes for change orders in highway construction. Construction Management and Economics, 22(5), 509–520. https://doi.org/10.1080/0144619042000202735

Zada, A., Tizani, W., & Oti, A. H. (2014). Building Information Modelling (BIM) - Versioning for Collaborative Design. Computing in Civil and Building Engineering. https://doi.org/10.1061/9780784413616.064

Appendices

Appendix A. Type of design change in Literature

In this Appendix, the type of changes as described in literature are given.

Table 10. Type of changes in projects as decribed in Literature

	Type of change	Definition	Mentioned by
A	Elective change	One may choose whether or not to implement	(Sun et al., 2004)
	Required change	There is no option but to make the change	(Sun et al., 2004)
B	Anticipated change	Planned in advance and occur as intended.	(Sun et al., 2004)
	Emergent change	Arise spontaneously and are not anticipated originally or intended.	(Sun et al., 2004)
C	Reactive change	The events when a change occurs and the project team starts to take actions to remedy the consequences of this change	(Motawa et al., 2007)
	Proactive change	The events when a change is likely to occur in a later stage, and the project team plans to minimise the disrup-tive effect of these changes	(Motawa et al., 2007)
D	Beneficial change	Result from value engineering exercises and can actually help to reduce cost, schedule, or degree of difficulty, are welcomed by the management team, since these changes benefit the project.	(Ibbs et al., 2001)
	Detrimental change	These changes reduce client value and have a negative impact on a project. Detrimental changes may occur when there are insufficient alternatives to the problem they present	(Ibbs et al., 2001)

Appendix B. Interview questions

For the qualitative part of the case studies, semi-structured interviews are conducted. This appendix gives an overview of the questions that are asked to the BIM expert and the contract manager of each case.

Interview questions BIM expert:

Allereerst dank voor uw medewerking. Tijdens dit interview ga ik u vragen stellen over het gebruik van BIM in relatie tot ontwerpwijzigingen.

Eerst een paar algemene vragen.

1. Wat is uw rol in dit project? Was u vanaf het begin betrokken bij dit project?
2. Werkt u met hetzelfde projectteam sinds het begin van het project?
3. Kunt u wat vertellen over het project en in welke fase het nu bevindt?

Nu ga ik u enkele vragen stellen over welke software wordt gebruikt en de kennis en vaardigheden van het project team.

4. Hoe definieert u BIM?
5. Hoe en in welke fase werd BIM ingezet in dit project?
6. Is er een BIM plan opgesteld?
7. Maakt het projectteam gebruik van BIM tijdens de uitvoeringsfase?
8. Loopt het ontwerp nog door?
9. Welke BIM software wordt gebruikt bij dit project?
10. Welk 4D software wordt gebruikt?
11. Gebruiken de onderaannemers ook BIM software?
12. Hoe zit het met de BIM kennis en vaardigheden van het projectteam?
13. Werden er clash sessies georganiseerd? En meetings waarbij een ontwerpwijziging wordt besproken met de modelleurs?

Nu volgen er een aantal vragen over het (technische) gebruik van de software.

14. Is het BIM model 1 geheel of worden ze naderhand geclusterd?
15. Zo ja, uit hoeveel sub-modellen bestaat het totaal model?
16. Hoe vaak werden de modellen geclusterd?
17. Werd er gewerkt met worksets en waren deze gekoppeld aan een aantal personen?
18. Hoe zit het met de schijfrechten? Kan iedereen alles wijzigen aan het model?
19. Zijn er objecten in het BIM model die na een bepaalde fase worden aangegeven als ‘’frozen’’ en is dit ook terug te zien in het BIM model? (LOD markering)
20. Werd er gewerkt met parametrisatie van objecten?
21. Is er een directe link tussen de CAD software en eisen van het project?

Als laatst volgen een aantal vragen over BIM, gerelateerd tot projecten en wijzigingen.

22. Welke ontwerpwijzigingen treden het meest op tijdens de uitvoering in dit project?
23. In het geval van ontwerpwijzigingen, wat zijn de oorzaken?
24. Als een wijziging moet worden doorgevoerd, is het bekend welke modelleur dan bezig is met dat deel van het project. Hoe wordt dit gecommuniceerd?
25. Worden wijzigingen altijd doorgevoerd in BIM, of gebeurt het dat het ‘’even snel’’ op 2D wordt getekend?
26. Ontstaan er problemen bij het doorvoeren van een wijziging in BIM en hoe worden die opgelost?
27. Krijgen BIM modelleurs een logboek van wijzigingen te zien en is dit leesbaar?
28. Wat zou u anders willen zien in deze procedure?

Interview questions Contract Manager:

Allereerst dank voor uw medewerking. Tijdens dit interview ga ik u vragen stellen over het gebruik van BIM in relatie tot ontwerpwijzigingen.

Eerst een paar algemene vragen.

1. Wat is uw rol in dit project?
2. Werkt u met hetzelfde projectteam sinds het begin van het project?
3. Kunt u wat vertellen over het project en in welke fase het nu bevindt?

Nu ga ik een aantal vragen stellen over BIM.

4. Hoe definieert u BIM?
5. Hoe en in welke fase wordt BIM ingezet in dit project?
6. Wat is een contractwijziging?

De volgende vragen gaan over de ontstane wijzigingen gedurende de uitvoering.

7. Wordt het UO getoetst of geaccepteerd door de klant voor uitvoering?
8. Wanneer leidt een afwijking (in het ontwerp) tevens tot een contractwijziging?
9. Leiden contractwijzigingen altijd tot ontwerpwijzigingen?
10. En wat verstaat u onder scope change? Is dat hetzelfde als een contractwijziging?
11. Welke ontwerpwijzigingen treden voornamelijk op tijdens uitvoering?
12. Zijn er ontwerpwijzigingen geweest sinds het begin van de uitvoering die grote impact hebben gehad op tijd en kosten?
13. Welke oorzaken hebben geleid tot deze wijzigingen?
14. Zijn ontwerpwijzigingen voornamelijk opdrachtgever gerelateerd of vanuit de opdrachtnemer?
15. Hoe worden deze wijzigingen gedocumenteerd?
16. Hoe werkt het proces van het doorvoeren van wijzigingen?
17. Wordt tijdens dit proces de PMI gehanteerd die op de BAM portaal staat?
18. Hoe wordt BIM ingezet bij het doorvoeren van wijzigingen?

Appendix C. Data set used in case studies

In this appendix, in Table 11 and 12, is shown which data is gathered to perform the quantitative study by using the data-tool: PowerBI.

Table 11. Registered data 'organisational dimension'

	Registered data	Reason to register
1. Number of change		
2. Initiator	Contractor, Client	
3. Formal notification date		In one case, the changes are implemented after formal notification from the client.
4. Sign date (change proposal)		In two cases, changes are implemented after signing the change proposal.
5. Sign date (final contractual change form)		If the final change form is signed, an agreement is reached on the costs of the change.
6. Time (in months) between observation date and sign date		This period of time gives an indication of how long the period was to make a decision and to agree on whether to implement the change or not and to make an impact analysis.
7. Time between sign date change proposal-final contractual change		This period of time gives an indication of how long the financial negotiations took.
8. Change request from..		This gives an indication of where the change is initiated.
9. Change request from.. (category)	E-mail from client Project meeting Design work Work preparation Construction work Review Design by Client	Change requests are categorised.
10. Cause		The cause is described in order to categorize in the next step.
11. Cause (category)	Clients change requests, Partially incomplete or erroneous project documentation/requirements, Contractors change requests, Change of regulations, Site related causes	The causes are categorised into 5 types in order to analyse them. Further description of these 5 cause categories are illustrated in chapter 3.
12. Reason of design change	Impact analysis, Implement into design, Change phasing of activities	Is this design change implemented in the design? Some changes are related to a design discipline. However, they are not implemented into the design. E.g. only the phasing of the activities is changed.
13. Consequence of design change	Work preparation is involved, Construction is involved, Maintenance is involved.	It is assumed that the process is disturbed through change, if it affects more disciplines as work preparation and execution work.

14. Change, cancellation or new requirement?	Yes, No	In case of scope change.
15. Realisation costs of change	€	To measure the direct effects of change.
16. Maintenance costs of change	€	
17. New planning according to change?	Yes, No	It is assumed that each change has time consequences. For each change, it is registered whether the planning is updated or not.

Table 12. Registered data 'Technical dimension'

	Registered data	Reason to register
1. Number of change		
2. Implemented in BIM3D?	Yes, No, Partly, N/A, Unknown	As this research focuses on the implementation of changes with the use of BIM, BIM 3D use with each change is registered.
3. Type of adjustment in BIM 3D?	1. Type of change: a. Addition; b. Modification; c. Deletion of objects. 2. Interface between objects: a. Analytical; b. Spatial. c. No interface 3. Component attributes: a. Geometry; b. Position; c. Specification.	By looking into the type of changes in BIM3D, per discipline, it becomes clear whether more scope is implemented; whether there are interfaces with other disciplines and what type of changes in components are registered mostly.
4. Design Discipline(s) related to change	Differs per case	Gaining insight in whether the change is multidisciplinary and which disciplines are related to the change.
5. If not implemented in 3D, the reasoning		Reasons for not implementing change can differ and are important to register as this can help to give correct recommendations at the end of this research.
6. Implemented in BIM 4D?	Yes, No	As this research focuses on the implementation of changes with the use of BIM, BIM 4D use with each change is registered.

Appendix D. Reference system of case studies

This appendix shows the used reference system in chapter 4: case studies. Hereby interviews are conducted during the qualitative and the quantitative study, see Table 13.

Table 13. Reference system

Case	Type of study	Abbreviation	Refers to	Date
A	Qualitative	[CM-A1]	Contract Manager	25-10-2018
		[DM-A5]	Design Manager	27-03-2019
		[BM-A2]	BIM Modeller Civil Engineering	11-10-2018
	Quantitative	[nCM-A1]	Contract Manager	15-03-2019
		[nBM-A2]	BIM Modeller Civil Engineering	05-04-2019
		[BM-A3]	BIM Modeller Roads	27-03-2019
		[BM-A4]	BIM Modeller MEP	04-04-2019
B	Qualitative	[CM-B1]	Contract Manager	30-11-2018
		[BM-B2]	BIM Manager	28-11-2018
	Quantitative	[nCM-B1]	Contract Manager	03-04-2019
		[BM-B3]	Engineering Manager Civil Engineering	03-04-2019
		[BM-B4]	Site Manager Roads	04-04-2019
		[BM-B5]	Engineering Managers A&M	04-04-2019
		[BM-B7]	Engineering Manager Rail	26-04-2019
C	Qualitative	[CM-C1]	Contract Manager	12-02-2019
		[DM-C2]	Design Manager	08-02-2019
	Quantitative	[nDM-C2]	Design Manager	04-06-2019

Appendix E. Further documentation of case studies

In this Appendix, further documentation is given of the quantitative analysis of the three cases.

1. Case A

In this case, the contractor is responsible for 30% of the design changes. The client is responsible for the client's change requests, partially incomplete documentation and site-related causes, together that is 69%. Change of regulations counts for 2%. Hereby, the client initiated 39% of the design changes and the contractor 61%. In the case of partially incomplete or erroneous documentation, the contractor initiated this change in 68% of the cases. This cause is namely discovered during design work or design meetings(71%), then in project meetings(14%), email from client(7%), and 7% are discovered during construction work. In general, most of the design changes are initiated during design work or design meetings (85%).

Clients change requests apply mainly on Roads and MEP and contractor requests changes primarily in the disciplines: Civil Engineering and MEP. Partially incomplete documentation has significantly more effect on the discipline Roads.

From the analysis, it appeared that costs increase significantly in the case that execution work is included in the design change. Within this sample, 65% have led to a change in the scope of work of execution works, 14% work preparation and 6% have led to a change to the maintenance works. In order from more to less impact at the total costs: Execution work, design work, work preparation, maintenance. Looking at the design disciplines, the realisation costs are the highest if MEP is related to the change, namely 44% of the total change costs. Furthermore, MEP also has the most effect on maintenance costs, namely 67% of the maintenance costs are from design changes within the discipline MEP.

From the interviews, it appeared that most of the design changes were implemented after both parties had signed the change proposal. The time that elapses between formal notification of the design change and agreement on the change by both parties has a median of 9 months. There are outliers up to 27 months. Fifteen of these design changes with outliers have been wrapped up together in one final change form. These changes are still separately analysed, as they all had different causes, and they were also separately implemented in the project.

If the change is initiated per email from the client, the duration till implementation of the change has a median of 13 months. In the case of design work, this is 9 months, Project meetings 8 months, Reviewing design 3 months. However, the actual duration of a change may be much longer, as the formal notification is in many cases a few months after the change is recognized within the project team.

So even if the design changes were observed early in the construction process, it takes time to agree on whose responsibility the change is and to map what the effects will be on planning and costs. Often it takes more time if the change is complex and if it is multidisciplinary. The implementation of some design changes has been started before the change proposal was signed. In this case, thus before the execution phase. One of these is explained in section 1a of this Appendix.

Discipline Roads has the highest share of changes with execution work(49%), and the planning is changed most(57%) when Roads is related to the change. After Roads, changes related to MEP led most to execution work, and then comes Civil Engineering.

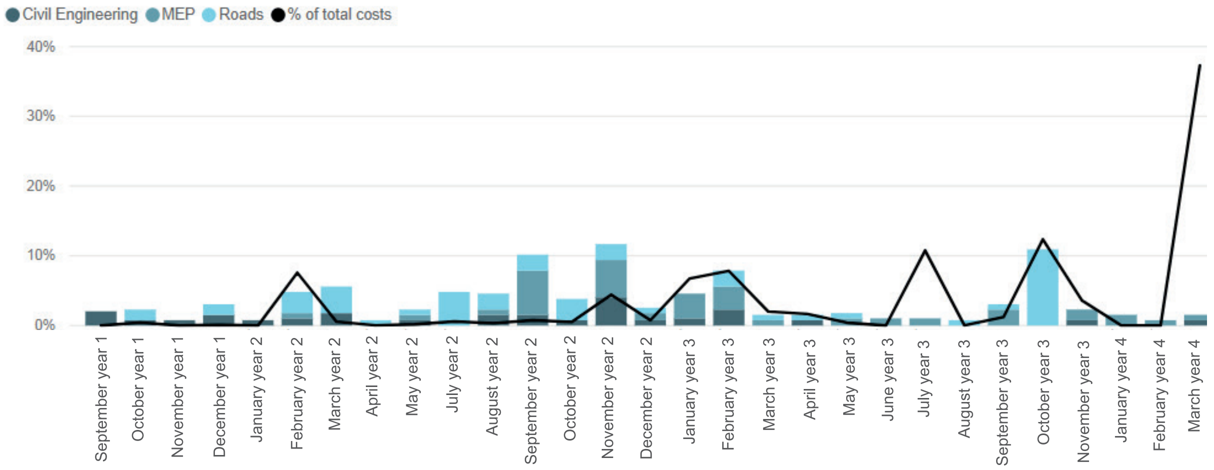


Figure 23 Implementation date of design changes per discipline in case A.

In Figure 23 is shown: The implementation date of the changes together with the costs. Despite that many design changes occur from May year 2 till October year 2, the costs are relatively low. The high costs at march year 4 are from change CW-B, see also section 1a of this Appendix. The high change costs at October year 3 result from the finalisation of negotiations of 15 design changes of the discipline Roads. These changes were already implemented in the project, early in the execution phase. The high costs in July year 3, result from a change in the discipline MEP.

Furthermore, according to the data, most changes to the disciplines of Civil Engineering and Roads were at the beginning of the project execution. From August year 2, discipline MEP implemented many changes. The amount of changes also decreases after March year 3. However, the changes that occur are costly.

BIM3D use

For the analysis of BIM3D use, distinctions are made for different type of design changes. Design changes usually led to modifications and addition of objects, see Figure 24. Deletion also occurs. Civil Engineering and MEP have most interfaces mutually, see Figure 25. If there is a modification, that is in most cases geometry within Roads and Civil Engineering, see Figure 26. Within MEP, changes in specification occur most. The reason that specification changes do not occur within discipline Roads is that materials and other specifications are not modelled in 3D. No trend can be seen in the usage of BIM 3D overtime during the project. However, if the Execution phase is included in the change, amount of BIM 3D use decreases with a few percent.

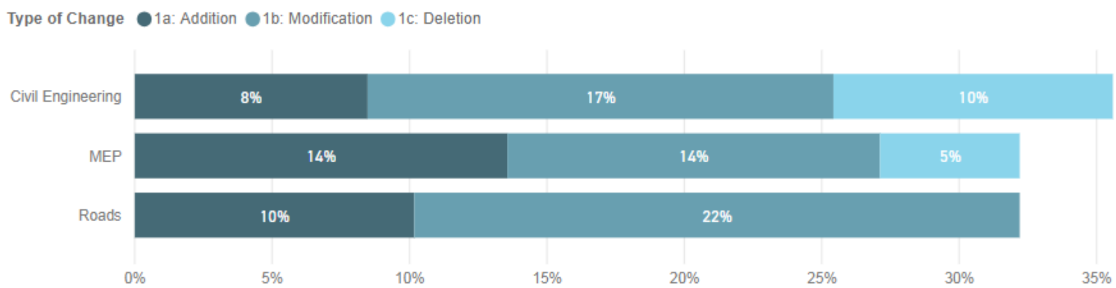


Figure 24 Type of design change in BIM3D, per discipline, in case A.

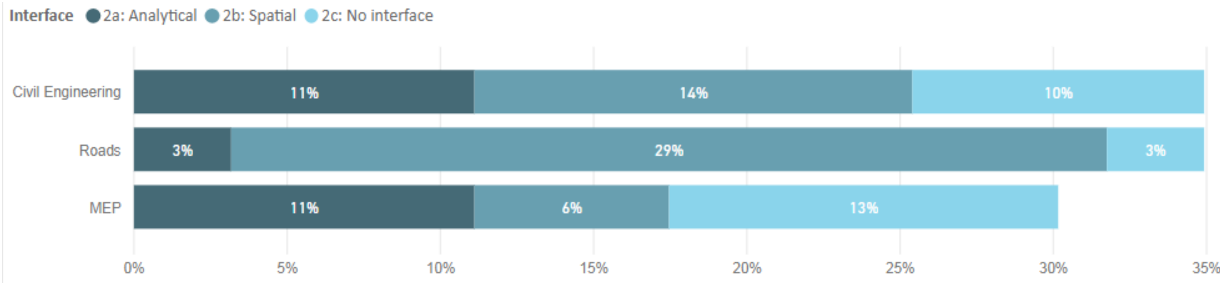


Figure 25. Interfaces in BIM3D, per discipline, in case A.

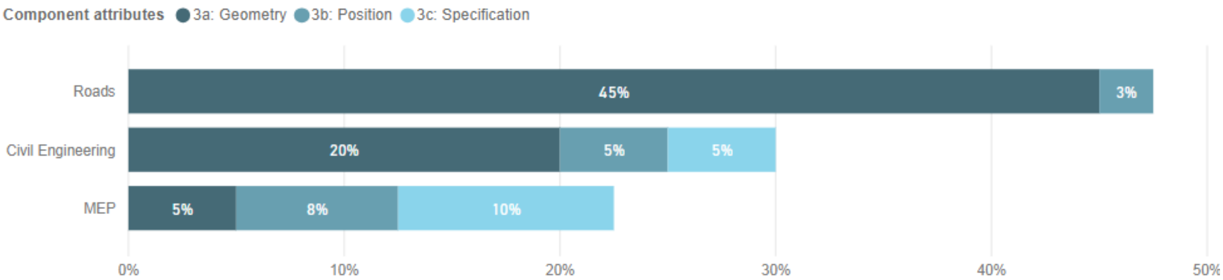


Figure 26. Component attributes, per discipline, in case A.

1a. Sample Analysis – Change description

CW-A:

[Confidential]

CW-B:
[Confidential]

2. Case B

The contractor is responsible for 3% of the design changes in this case. The client is responsible for the client's change requests, partially incomplete documentation and site-related causes, together that is 94%. Change of regulations counts for 3%.

Hereby, the client initiated 80% of the design changes and the contractor 20%. In the case of partially incomplete or erroneous documentation, the client initiated this change in 75% of the cases. The contractor mainly initiated Site-related causes. How the change is requested is not documented in this case.

All design changes from this sample have led to a change of scope of the execution work and work preparation, according to the contract manager. The financial impact of execution work and work preparation cannot be determined, as all changes have the same impact. However, the costs per cause can be illustrated. That is as following: the cause client change requests count for the majority of the costs (66%) and has the largest share in extra costs made for construction work. Then comes Partially incomplete documentation(18%), Site related causes(14%), Change of regulations(1%) and contractors change requests(1%).

Design changes, in this case, were implemented, immediately after formal notification. The time that elapses to agree on the financial side has a median of 5, with outliers of 20 months. Hereby, contractors change requests have a median of one month between formal notification and financial agreement. The rest of the causes differ from 5 (clients change requests) to 8 months(site related causes). From all disciplines, discipline E&P has the highest median, namely 7 months.

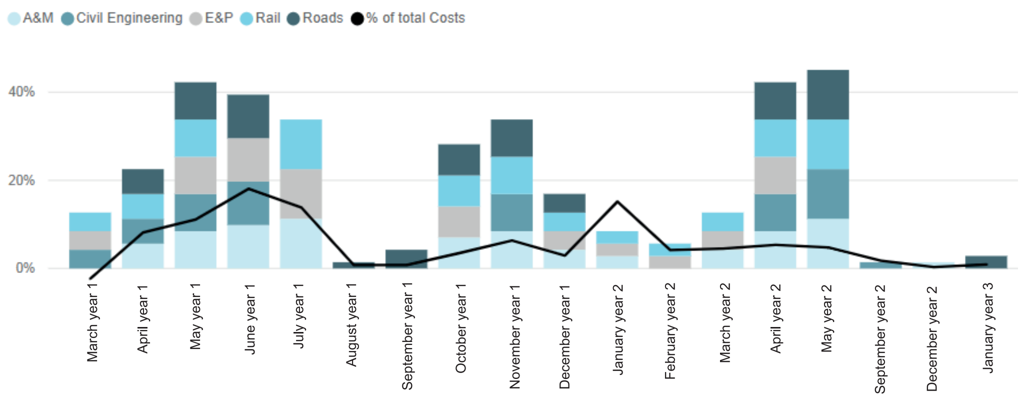


Figure 27. Implementation date of design changes per discipline in case B.

In Figure 27 is shown, which disciplines were related to the design changes over time. The line in the graph indicates the costs per month. Civil Engineering had mainly changes till June year 1. A large part of the incurred expenses in June year 1, are on account of discipline Civil Engineering. The high costs in January year 2 follow from 2 design changes. These changes are related to A&M, Rail and E&P. Except for Civil Engineering, the rest of the disciplines have changes over the entire period.

BIM3D use:

If (partially) implemented in 3D, most occurring type of changes are modifications to objects, see Figure 28. Disciplines Civil Engineering and Rail have relatively more additions of objects. Deletion of objects only occurred within the discipline A&M. Roads has the least interfaces with other disciplines. A&M, Civil Engineering and Rail have substantially the same share of interfaces mutually, see Figure 29.

If there is a modification of an object within a discipline, this is in most cases a change in the geometry, a change in specification in A&M, Civil Engineering and Rail. And change of position within A&M and Roads, see Figure 30. Except for rail, no specific trend can be seen in BIM3D usage over time. As to Rails, the 4 changes that occurred from October year 1 till January year 2 are not implemented in the 3D model. However, looking into the reasons why it is not implemented, it becomes clear that these changes concern changes in e-plan. These changes are not included in 3D.

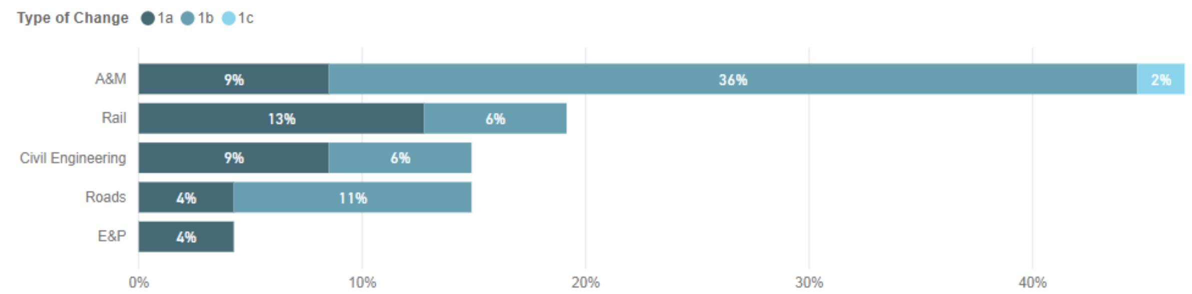


Figure 28.Type of Design change in BIM3D, per discipline, in case B.

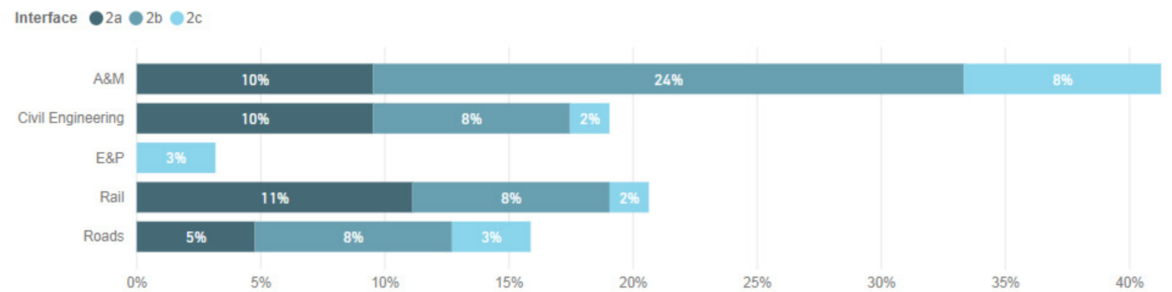


Figure 29.Interfaces in BIM3D, per discipline, in case B.

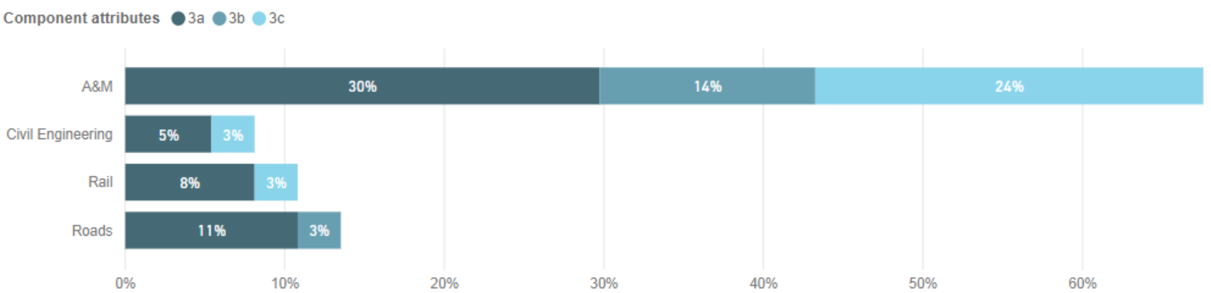


Figure 30. Component attributes in BIM3D, per discipline, in case B.

3. Case C

The client initiated 14 design changes and the contractor 1. In the case of partially incomplete or erroneous documentation, the client initiated this change in 5/6 of the cases. How the change is requested is not documented in this case.

Clients change requests apply mainly to Rail. The contractor only requested 1 change in Rail. Partially incomplete documentation has an effect on both Rail and Civil Engineering. Within this sample, 7 of the 15 design changes have led to a change of scope of the execution work. Hereby 2 changes led to a change in the work preparation.

One of the design changes discussed here is still not agreed financially. The price of the change is taken from the change proposal. In Figure 31, it can be seen that this change has the highest costs and is related to the Temporary Facilities. As the project is finished, the change is already implemented.

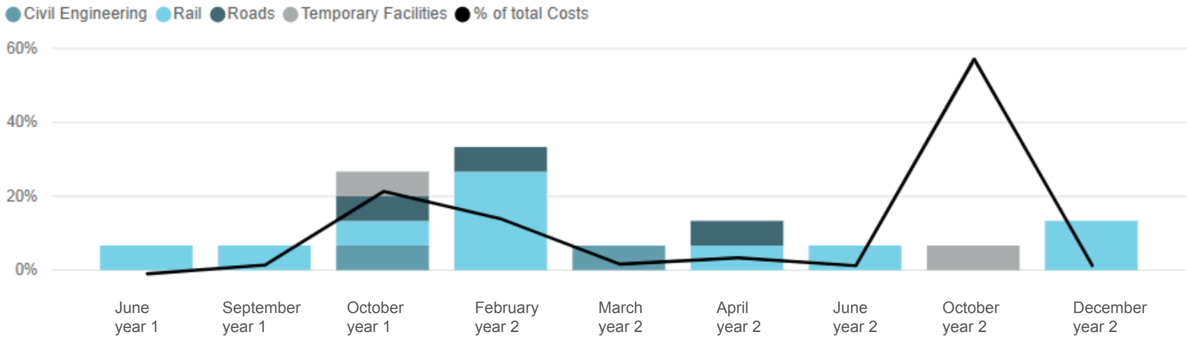


Figure 31. Implementation date of design changes per discipline in case C.

Both contractor and client have requested changes during the course of the project execution. There is no specific trend recognizable.

BIM3D use:

Discipline Roads has had an addition to the design; the remaining of the changes were modifications to objects within the design, see Figure 32. Discipline Rail has the least amount of interfaces, see Figure 33. As shown in Figure 34, most changes were related to the geometry of objects.

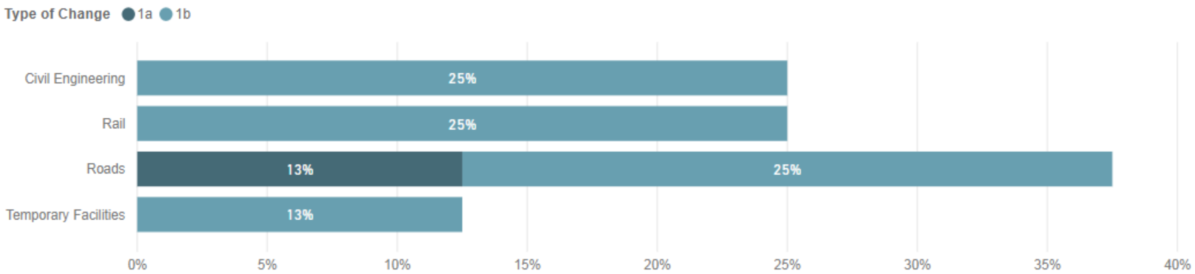


Figure 32. Type of design changes in BIM3D, per discipline, in case C.

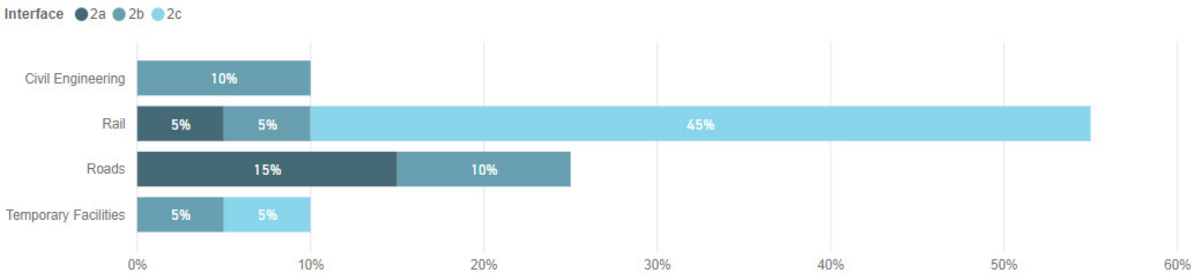


Figure 33. Interfaces in BIM3D, per discipline, in case C.

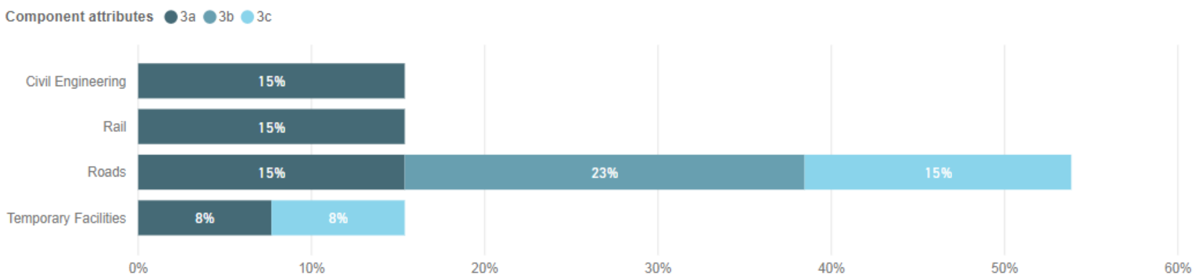


Figure 34. Component attributes in BIM3D, per discipline, in case C.

Appendix F. Use of BIM during project phases

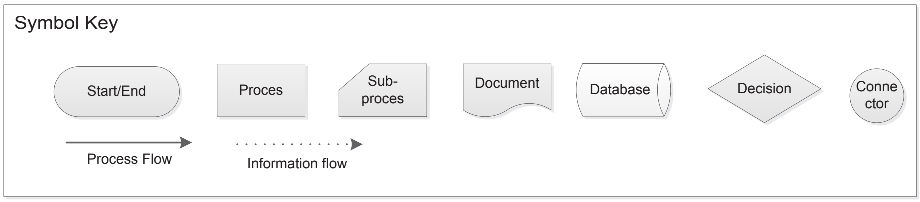
In this appendix, an overview is given for each case, per project phase, to what extent BIM is used. See Table 14.

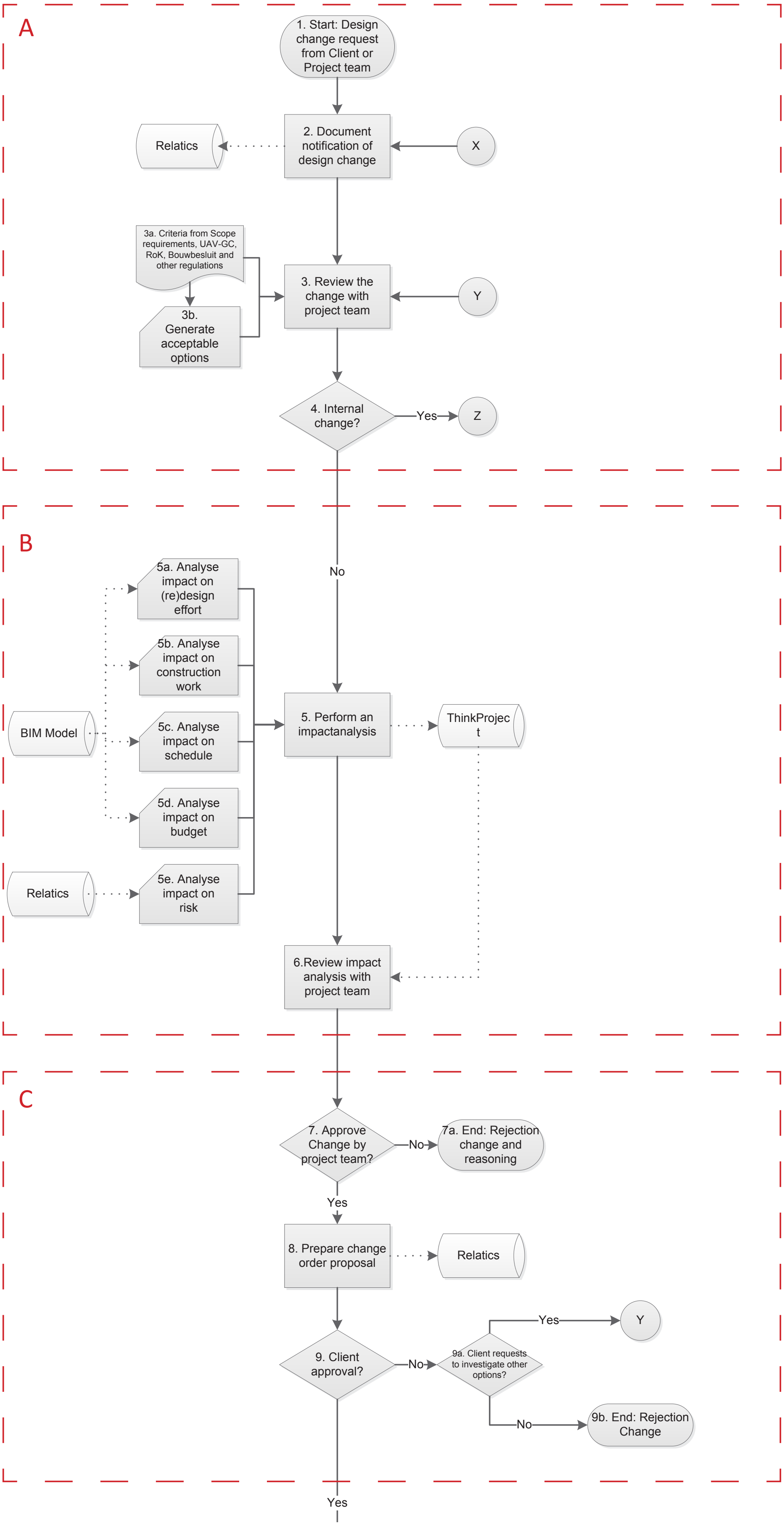
Table 14. Use of BIM during project phases

Phase	Case A	Case B	Case C
Tender	No use of BIM3D. BIM Plan (draft)	No use of BIM3D.	Basic BIM3D model to gain insight in quantities. BIM Plan (draft)
Design	BIM Plan (agreements regarding BIM with the project team) Use of BIM3D BIM 4D is modelled for the critical parts and not updated hereafter.	No BIM Plan, only a Revit plan and a BIM demarcation table Use of BIM3D BIM 4D is modelled for the critical parts and not updated hereafter.	BIM Plan(agreements regarding BIM with the project team) Use of BIM3D BIM 4D is modelled for the critical parts and not updated hereafter.
Work Preparation	No to little usage of BIM3D	No to little usage of BIM3D	Quantities taken from both 2D and BIM3D
Execution	Surveyors use BIM 3D. Each drawing that is used on-site contains a QR code. The site manager has to check, by scanning the QR code, whether the drawing is still up-to-date. In case that changes have occurred. 3D renders and sections are visible on the 2D drawings that are used on site.	Surveyors and some site managers use BIM 3D.	Surveyors and some site mangers use BIM3D. On site, BIM360 is used for the examinations. These examinations were directly imported in the 3D model per object.
Maintenance	For the maintenance contract, as-Built is drawn in 3D. No 3D as-Built is requested by the client in the contract.	No maintenance contract. The client requests the as-Built in 3D. All deviations have to be included in this model.	No maintenance contract. No 3D as-Built model.

Appendix G.

Figure 35. Procedure used during expert assessment





1.Start: Design Change request from Client or Project Team.

2. Document Notification of design change in Relatics.
The contract manager documents the date of request, the cause of change, the scope of change and the concerned disciplines in Relatics.
- X: If in step 29, a deviation is found.

3. Review the change with project team.
A meeting is initiated in which acceptable options are generated based on the requested change and criteria(scope requirements, UAV-GC, RoK, Bouwbesluit and other regulations.

In this meeting an acceptable option is chosen and also it is determined whether the change is internal or needs client approval.
- Y: If in step 9a, the client wants other options to be investigated. Or if in step 31 and 32 the change is not approved after construction.

The actors involved at this step are the contract manager, construction manager, concerned design leaders and in case of a multidisciplinary change the design manager.

4. Internal Change?
-Z: If the change does not need client approval, then the change is immediately implemented > step 10.

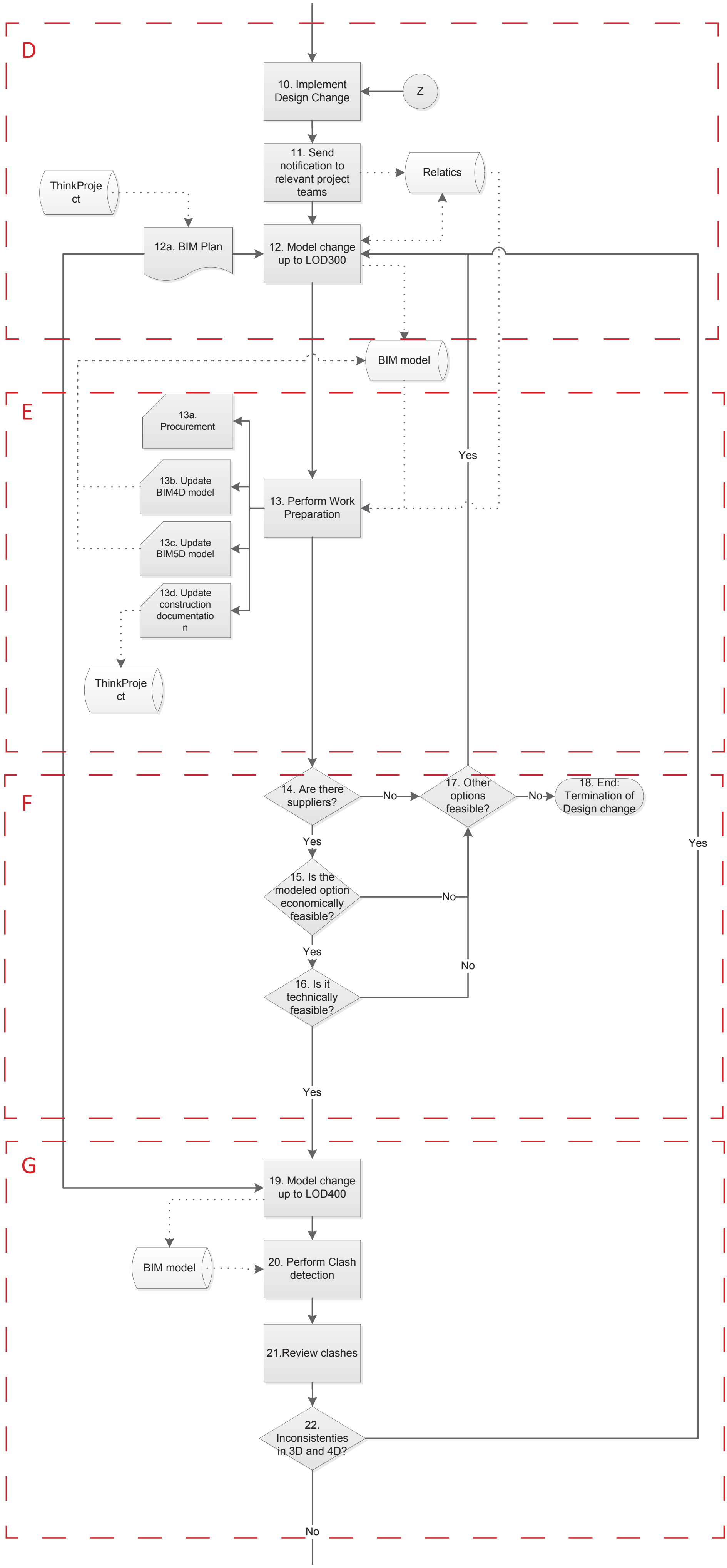
5. Perform an impact analysis
During this step an impact analysis is performed. Hereby, the impact on design effort is determined by the concerned design leaders and design manager. The impact on construction work is determined by the construction manager. The impact on schedule is determined by the BIM 4D modeler (planner). The costs are determined by the BIM5D modeler(cost engineer) and the risks by the risk manager. The results of the impactanalysis are included in a document, which is uploaded to ThinkProject.

6. Review impact analysis with project team
During this review session, the impact analysis document from ThinkProject is used. The construction manager, contract manager, design manager and design leaders are involved in this review session. Whether the risks and costs are acceptable are decided by the project manager.

7. Approve change by project team?
If the change has an inacceptable impact on the project constraints, then the change may be rejected. The reasons of rejection should be communicated by the contract manager to the client.

8. Prepare change order proposal
The contract manager drafts a change order proposal and uploads this to Relatics. In this proposal, next to the cause and the scope of change, time and cost effects have to be made clear. The amount of time needed to implement the change has to be included in this proposal. So the client is aware of possible consequences.

9. Client approval
If the client does not give approval, and does not want the project team to investigate other options, the change process will end.
-Y: If the client requests to investigate other options then stated in the proposal, the project team will review the change by generating other possible options>step 3.



10. Implement design change
If the client approves, or in case of internal changes, the design change can be implemented.

11. Send notification in Relatics
In Relatics, all relevant disciplines that were already entered in step 2 of this process are notified. This notification is sent by the contract manager through Relatics. In this way, departments are already informed that a change has to be implemented soon. The relevant teams will receive a pop-up alert in Relatics.

12. Model Change up to LOD300
The design team that is notified by Relatics, will model the change up to LOD300 in BIM3D according to the BIM Plan. In Relatics the design team has to register:
- The start date of implementing the change in the design
- The amount of modelers working on the change

*If drawing in 2D, place the link (to Thinkproject) of the 2D detail in the properties box of relevant object(in BIM3D).

13. Perform Work Preparation
During this stage of the process, the work preparation team will purchase materials needed and look possibly for any sub-contractors or suppliers. Also, the effects in time and costs are modelled in BIM and construction documentation is updated.

14. Are there any suppliers?
If during procurement, it appears that no suppliers can be found to construct the change: Other design alternatives have to be generated.

15. Is the modelled option economically feasible?
If during work preparation it appears that the chosen option is too costly in contrast to what was determined in the change proposal, other design alternatives have to be generated.

16. Is the construction technically feasible?
During BIM4D modelling, it may appear that it is not possible to construct the chosen design alternative. Other options have to be taken into account.

17. Other options feasible?
If no alternatives are possible, the change process will end. If possible, the change has to be modelled again up to LOD300.

18. End: Termination of design change
The contract manager arranges with the client the termination of the change.

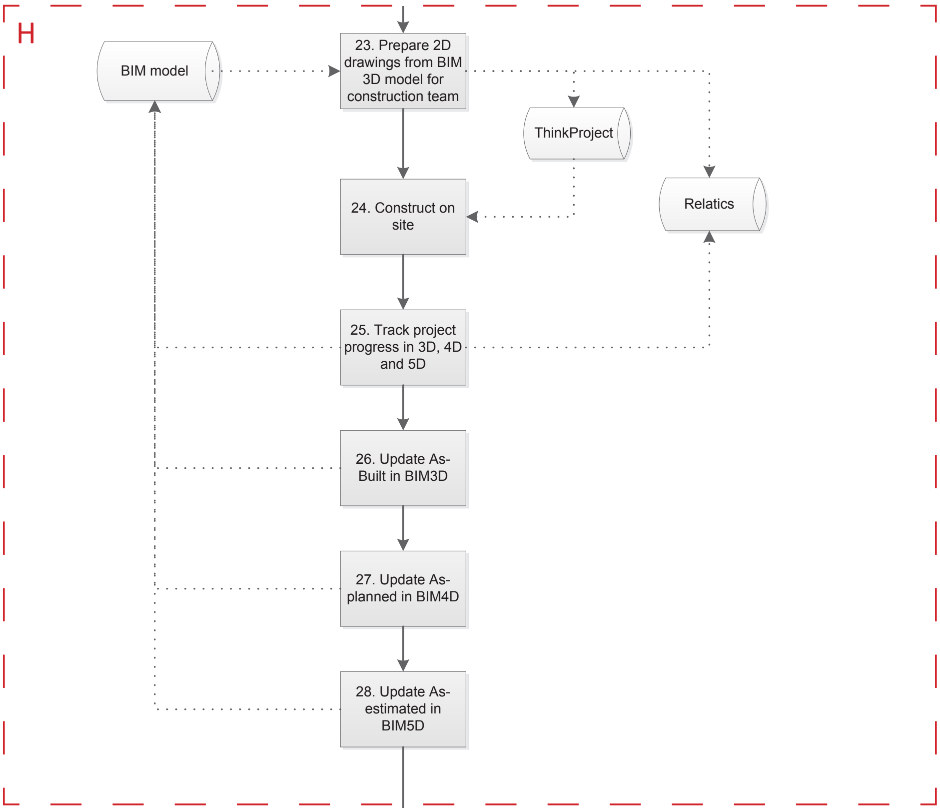
19. Model change up to LOD400
If there are suppliers and the modelled option is feasible, then the change can be together with the input from work preparation be further modelled up to LOD400. The input is then e.g. the specifications of objects that are determined by manufacturers. Also here, the objects are modelled by the design team in BIM3D based on the BIM Plan.

*If drawing in 2D, place the link (to Thinkproject) of the 2D detail in the properties box of relevant object.

20. Perform clash detection
Automatic detection in 3D and 4D. This step is even more important if no interfaces are visible in software of each discipline and in case of multidisciplinary design changes.

21. Review clashes with project team
The clashes are discussed in an initiated meeting with the design team and Work preparation.

22. Inconsistencies in 3D and 4D?
If there are inconsistencies in 3D and 4D between the sub-models, then the design team should solve this problem. Also Work Preparation, may have to solve clashes in their models.



23. Prepare 2D drawings from BIM3D model for construction team.
If the models do not contain any clashes or errors, then 2D drawings can be extracted from the BIM3D model by the design team, to be used by the construction team. These 2D drawings are uploaded to ThinkProject.
- The design team has to register in Relatics: the completion date of the change.

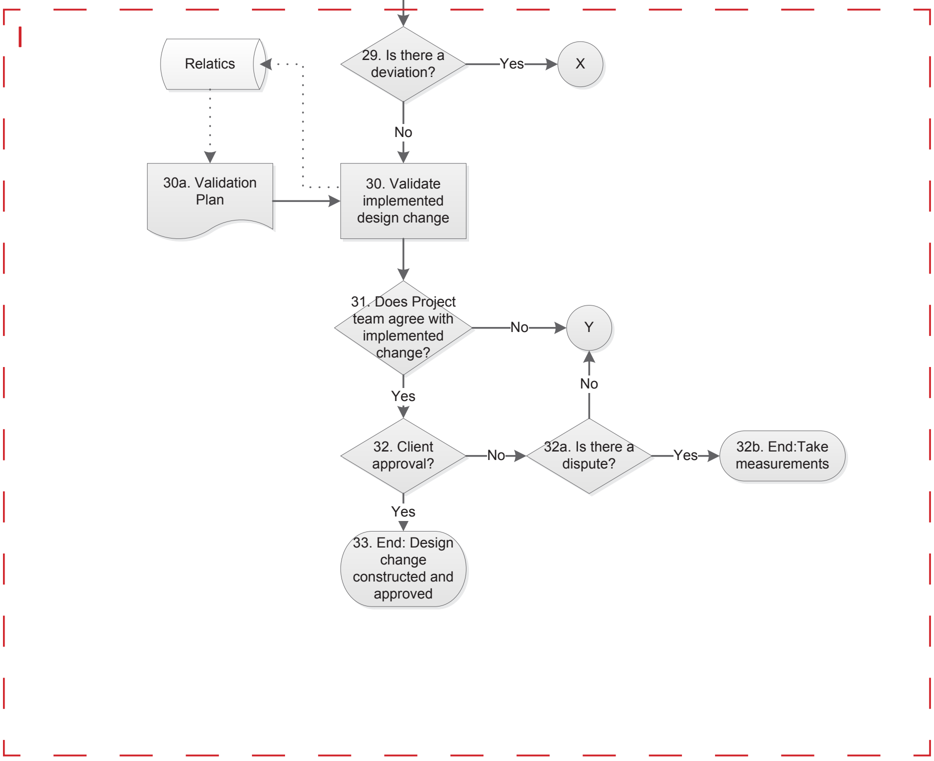
24. Construct on site
As soon as the drawings are uploaded the sitemanager is notified by ThinkProject, so the drawings can be downloaded and used on site.

25. Track project progress in 3D, 4D, 5D
The project progress is reported in Relatics. However, due to the live link with the BIM model, the progress updates can also be seen in the properties box of each object.

26. Update as-Built in BIM3D
After construction, as-Built is modelled in BIM3D. Hereby, LOD's are updated and objects within the model are changed if necessary.

27. Update as-Planned in BIM4D
After construction, as-planned is updated. This is an important task as it gives insight in whether the determined planning was accurate and will give input for future planning of similar activities.

28. Update as-estimated in BIM5D
After construction, as-estimated is updated. This is an important task as it documents whether the determined costs of the change are accurate and will give input for future estimating of similar activities.



29. Is there a deviation?
If during construction, deviations are observed, then these have to be documented by the contract manager and reviewed by the project team > step 2. If no deviations are found, then the implemented design change can be validated.

30. Validate implemented design change
The implemented design change is validated in Relatics, based on the validation plan.

31. Agree with implemented change?
Based on the validation, the project team decides whether the implemented change is according the determined scope and requirements. If the project team does not agree with implemented change, then the change should be reviewed again>step 3.

32. Client approval?
After validation and agreement within the project team, the client is asked for approval.

32a. Is there a dispute?

32b. End: Take measurements
Court proceedings can be initiated if no agreement can be reached.

33. End: Design change constructed and approved
If the client approves, the design change process ends.

Appendix H. Suggested changes during expert assessment.

Table 15. Implemented changes in procedure

	Suggested changes that are implemented	How is it implemented in the procedure?
Part A	The impact analysis must also be performed for in-ternal changes.	In the optimised procedure, all changes have to go through an impact analysis.
	Internal changes should also have approval of pro-ject team to proceed.	In the optimised procedure, all changes are asked for project team approval.
	Generating options (in step 3) has to be done based on time, budget and risks.	Added to specifications.
	In case of major changes, you may want to ask the client to pay for the impact analysis.	As the number of changes has to be limited, in optimised procedure, all changes that need client approval have to go through an impact analysis that the client has to pay for. If the client does not pay, the project team rejects the change. This is possi-ble, according to the UAV-gc.
Part B	Now only design, construction, budget, time and risks are taken into account during the impact analysis. However, there is more that should be taken into account, such as EMVI, stakeholder management etc.	In the specifications is indicated that all relevant documents named in the contract should be con-sidered during the impact analysis.
	When analysing the impact of the change on the design, it must also be considered in which stage the design is.	Added to specifications.
Part C	A change cannot simply be rejected. This is done on the basis of the conditions set in UAV-gc.	Added to specifications.
	The changed scope requirements and risks have to be entered in Relatics.	Added to specifications.
	If the change does not need client approval and is rejected, who communicates this to the project team?	Added to specifications.
Part D	It is not clear what happens at step 12, if the change only concerns LOD400.	Here a step is added. If the change only concerns LOD400, project team can proceed with work preparation.
	Work-preparation team must already be involved in this part of the procedure. For example, an initiated meeting with the design team, work preparation team and construction team. Hereby, the option that is approved with the impact analysis is further dis-cussed into detail on how the change has to be im-plemented into the design and construction.	A coordination meeting is added.
	After LOD300, the project team has to verify wheth-er the design meets the (adjusted scope) require-ments.	Project team approval is added.
	In the contract, it is often specified whether the client must be asked for approval and for which particular stage of the design or construction. This means that this should also be implemented in the procedure.	Client approval is added.

Part D	There should also be a clash detection after LOD300.	Clash detection for LOD300 is added.
Part E	Procurement should register everything in Relatics	Added link to database.
Part F	More decisions are possible here: e.g. if the risks are acceptable, the quality is acceptable etc.	These steps are deleted, and the decisions are placed in specifications, as these occur in the whole process.
	These decisions must be continuously made as the processes are iterative in nature. Suggested is to move this part to part C or to place it in specifica-tions.	
	Step 18 is not possible, as the moment that a con-tractual change is signed, the risk has been adopted. No cancellation of the change is then possible any-more.	This step is deleted. Cancellation is only possible in case of an internal change. However, this hardly occurs in this stage of the process.
Part G	Verification process also applies for LOD400.	Project team approval added.
	Step 19 info can be gathered from ThinkProject for the construction documentation and Relatics for the suppliers.	Links to databases are added
Part H	Deciding about deviations should take place during construction.	Deciding about deviations can take place after in-spection on site.
Part I	To only validate in this step is not correct. This should mainly be done in previous steps. Validation is also possible in this step.	Client approval added for both LOD300 and LOD400.
Other	Be consistent with the input and output lines in the flowchart.	To make it more readable, input and output lines are more consistent in the new procedure.
	Add a short introduction about this procedure.	A short introduction is added.

Table 16. Not implemented changes in procedure

	Not implemented suggestions:	Reason for not implementing
Part C	If the change is not approved, you have to go back to step 3. Here again is asked at step 4, if the change is internal or not. This is unnecessary.	In the optimised procedure, this also occurs. This cannot be removed, as the goal is to inte-grate the processes. Otherwise, two different processes will be displayed that are nearly the same. In optimized procedure, in step 4, this is registered in Relatics, and in step 11 in Relatics, it can be seen if the change is internal or not.
Other	A document (change order) is missing in the flowchart.	Documents are not displayed in the flowchart. These are part of the information flows.
	A comprehensive process is not possible. Some parts of this process already exist, is it not possible to refer to these?	The goal here is to integrate more processes to one, so that the project team is aware of all the processes that have to take place. Existing processes do not have links to databases and therefore do not give sufficient information on how, where, and which information has to be shared by whom.
	This procedure only looks in BIM for analysing and implementing the change. However, there are more analyses that have to be performed in more systems.	The objective of this procedure is that BIM includes all databases which must be linked to each other. So if an analysis is done, this is performed in one of the databases that are part of BIM.