BIM as a communication and collaboration tool for the design and operation phase of hospital buildings

A case study research into validating and verifying the design and BIM model by the project team and client & end-users

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Mentors: Jelle Koolwijk & Clarine van Oel

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Abstract/summary

According to literature, the benefits of BIM can be well found in complex projects such as healthcare. When well implemented, the use of BIM as a tool for communication and collaboration can lead to a higher design quality and quality of the realized building, as well as increased efficiency and costs savings.

BIM can be used for integrated communication and collaboration between different stakeholders, from the same as well as from different project phases. For a good collaboration with BIM, clear objectives should be communicated between stakeholders. With BIM, project team actors can work together in a shared environment, existing of a 3D model and other tools. The project stakeholders can be architects, engineers, (sub)contractors, but also new roles that emerge due to BIM, such as BIM managers and BIM designers. Existing roles of project actors, such as architects, can also change because e.g. different technical BIM related skills are required. BIM can be used for information management between these different roles of the design team and the client and its end-users.

Considering the project lifecycle, the design and operation phase are critical because in the design phase the usability for the use phase is defined, and the use phase is the longest phase of building projects. BIM can be used for communication between the different actors that work in the design and use phase. Also, end-users can be included in the communication about design and operation of buildings, to make a building better fit to the end-use. When communicating about the design and its specifications, the design and corresponding BIM model should be validated and verified.

Although a lot of benefits are given in literature**, the findings** of empirical research show that these benefits are often not met in practice: interviewed stakeholders stated that the benefits are not always working out as proposed by BIM programme makers, and the connection between design and use with BIM is often not implemented well enough, e.g. due to different information needs of different actors.

The process of communication in the project, as well of the way stakeholders validate and verify the design, are influenced by the project context, including language, culture, background and interests of different stakeholders. Further, incidents during the process can influence the extent that the BIM documents such as protocols and execution plans, as agreed upon in the start of the project, are followed during the project. Critical points towards a successful project are: 1. To use BIM as a means, instead of a goal in itself: the reasons why BIM is used should be well defined upfront, and good agreements should be made about it.; 2. BIM is not only a way to resolve design errors, but also to involve different stakeholders, including the client. The interests and competences of different actors should be defined upfront; 3. If the client does not have extensive knowledge of BIM, or does not know exactly why and how to use BIM, it is also up to the design team to help the client sort this out. 4. BIM and digital communication should not replace real life communication, as it stays important to meet face to face.

CONTENT

1. Introduction

Serious problems arise still in healthcare building projects, for example projects go over budget, experience delays, or a too low quality is established considering flexibility, energy efficiency and the satisfaction of end-users. A critical aspect of these problems is the communication between different project actors, that operate in the same or different building phases, and who all have their own competencies, technical knowledge and specialized jargon (Edmonson and Nembhard 2009, Sebastian 2011).The former leads to a long and difficult process of extracting, interpreting, and communicating complex design information in documents and drawings (Sebastian, 2011).

As stated by Mershbrock & Munkvold, complex projects such as hospitals are projects in which benefits of BIM can well be found (Merschbrock & Munkvold, 2015). If BIM is well implemented, the collaboration between actors who work with BIM can lead to a higher design quality and quality of the realized building, as well as increased efficiency and costs savings (Mershbrock & Munkvold, 2015; Huang, Yien, Chen, Su & Lin, 2017).

Building Information modelling (BIM) is software for information management and 3D modelling (Wong & Zhou, 2015), which can include tools, applications, activities and procedures (Papadonikolaki & Van Oel, 2016) that can form a platform to facilitate communication, and sharing and management of building information between various project stakeholders. (Papadonikolaki & Van Oel, 2016). BIM can be used for the different parts and activities involved in a facility, building or asset (Merschbrock & Munkvold, 2015, p1).

For instance, BIM can be used to make an integrated collaboration for various stakeholders. *(*Merschbrock et al, 2016). With BIM, actors can work together in a shared environment, existing of a 3D model and other tools. For a good collaboration between project actors that work with BIM, clear project objectives should be communicated amongst them. Communicating requirements can be done for instance through documents such as BIM protocols (Cavka, Straub & Pourier, 2017; Merschbrock & Munkvold, 2015; Merschbrock Lassen, Tollness & Munkvold, 2016).

Due to BIM, new roles emerge, such as BIM managers, BIM designers, BIM coordinators, and BIM technicians. Stakeholders that work with BIM can also have traditional roles, such as architects, engineers, and (sub)contractors. However, the roles of existing actors change because of working with BIM (Papadonikolaki & Van Oel, 2016; Sebastian, 2011). For a well-functioning communication and collaboration, different technical BIM related skills are required, but also communicative and interpersonal competences (Papadonikolaki & Van Oel, 2016, Edmondson and Lei, 2014).

Considering the life cycle phases, the design phase and the use (also: operation or maintenance) phase are critical, because in the design phase the functionality for during the use phase is defined, and the use phase is the longest phase of a building project. BIM can be used in the design phase to communicate functional specifications, which should lead to a well-functioning building during the use phase (Huang, Yien, Chen, Su & Lin, 2017, Peng, Lin, Zhang, & Hu, 2017). Further, BIM can be used for communication between actors that

work and operate in different project phases: for instance the design team and actors that use the building when it is finished. A 3D interface can be implemented to include end-users in the communication about design and operation of buildings, thus to make a building better fit to the end-use (Merschbrock & Munkvold, 2015).

One aspect of communication is validation and verification of the BIM model and the design and their specifications. Validation means that the (design or BIM) model meets the set requirements for functionality during the use of the building; verification refers to the fact that the (design or BIM) model is correct and correctly implemented (Sargent, 2013).

When looking at the former statements, BIM seems to have a lot of potential, however, it is shown many times in literature that these expectations are often not met, mainly because of the lack of good communication between actors, who operate in the same or different building phases (Sebastian, R., 2011; Huang, Yien, Chen, Su & Lin, 2017; Papadonikolaki & Van Oel, 2016; Peng, Lin, Zhang, & Hu, 2017)

Thus, the aim of the research is to get a better insight in – and if possible to improve – the processes of communication and collaboration between the different stakeholders (design team, client and end users) from the design and use phase of hospital projects in which BIM is used: more specifically in the way they validate and verify the functionality of the design and the readiness of the BIM model for the use phase. In the empirical part of this research, it is investigated which factors play a role in the success or failure of the former. For this specific subject, little research has been done: extensive literature is available about the communication with BIM, however not much is written about the validation and verification between the design team and client or end users in hospital projects, while they use BIM. All in all, this leads to the following main research question:

In what way are the **functionality of the design of hospital buildings, and the suitability of the corresponding BIM model** for the **use (phase), validated and verified** between the **various stakeholders,** while they (may or may not) use **BIM**, and what are the **critical points** for a **successful process**?

To address this question, two case studies are investigated: one hospital in the Netherlands, and one Foreign hospital project. During these case studies, project meetings are observed, and interviews with professionals are held, to find out which issues are experienced by various stakeholders of the two projects.

To answer the research question, the following parts are included in this report: a theoretical framework to frame the research subject, research methodology - including problem statement and relevance, aim of the research, theoretical perspective or conceptual model, research questions, research method, ethical considerations, findings of case observations and interviews, a discussion and a conclusion with recommendations for future (BIM) implementation.

2. Theoretical framework and research gap

Theoretical Framework

The following theoretical concepts form the framework of this research: Building Information Modelling, Complex (Hospital) projects, communication and collaboration with BIM – connected to roles and competences of project actors, communication with BIM in hospital projects: project phases and project actors, data exchange, and validation and verification.

Building Information Modelling: What is BIM and why is it relevant?

BIM can be used for multi-disciplinary coordination, 3D design integration, cost estimation, scheduling of construction, building operation performance and facility management (McArthur, 2015). Below some images are shown to give a representation of what a building information model can look like.

Figure 1 and 2 show 3D models of architecture and MEP (Mechanical Electrical Plumbing).

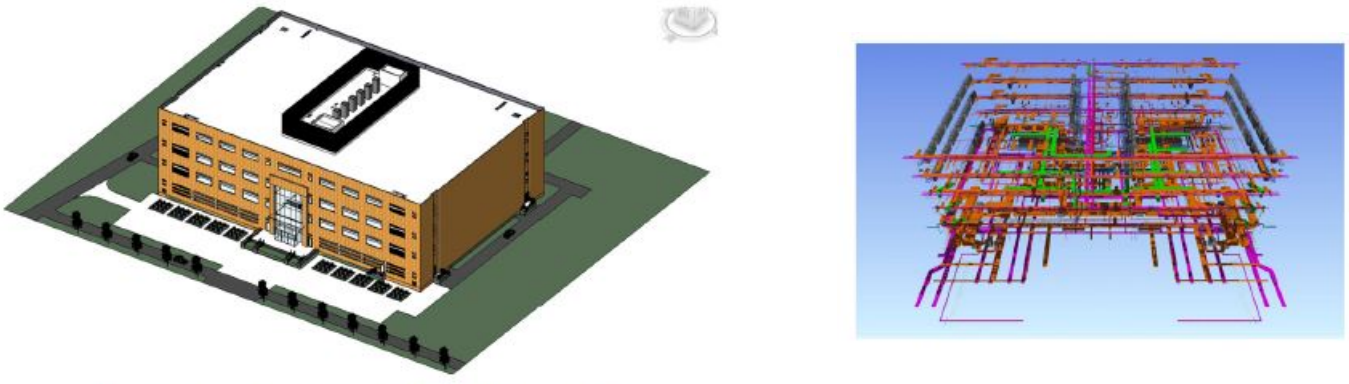


Figure 1. Architecture 3D model and MEP (mechanical electrical plumbing) 3D model. (Wang et al, 2016, p 138)

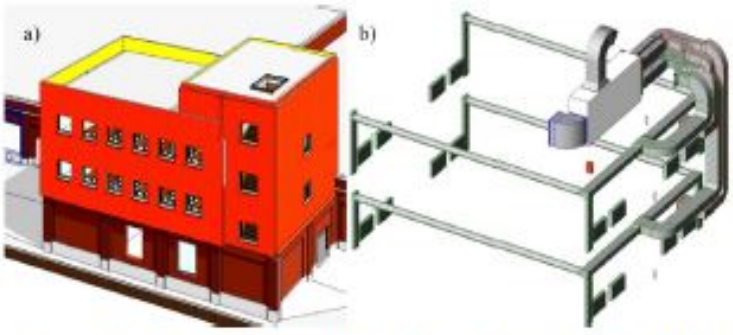
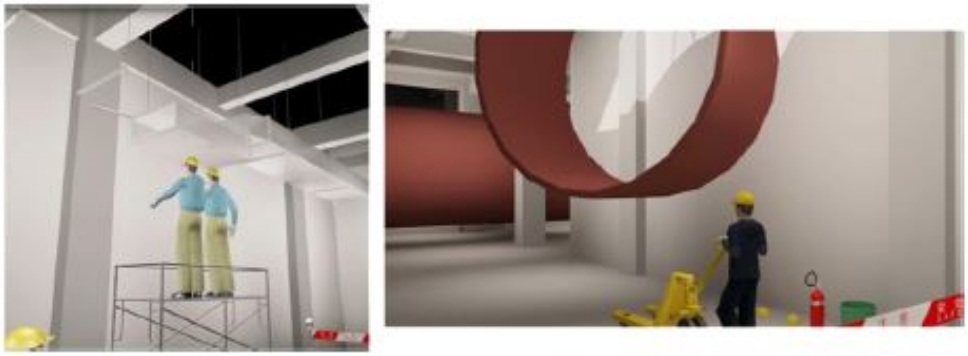


Figure 2. Building envelope 3D model and ventilation system model. (Andriamamonjy et al, 2018, p 176)

BIM programs can also be used for simulations, as shown in figure 3.



(a) Duct Installation Simulation (b) Ice-storage Cooling Tank Installation Simulation

Figure 3. Representation of digital simulations. (Wang et al, 2016, p 142)

In figure 4, a BIM model of a building construction is shown. In figure 5, a possible BIM process of MEP design is shown.

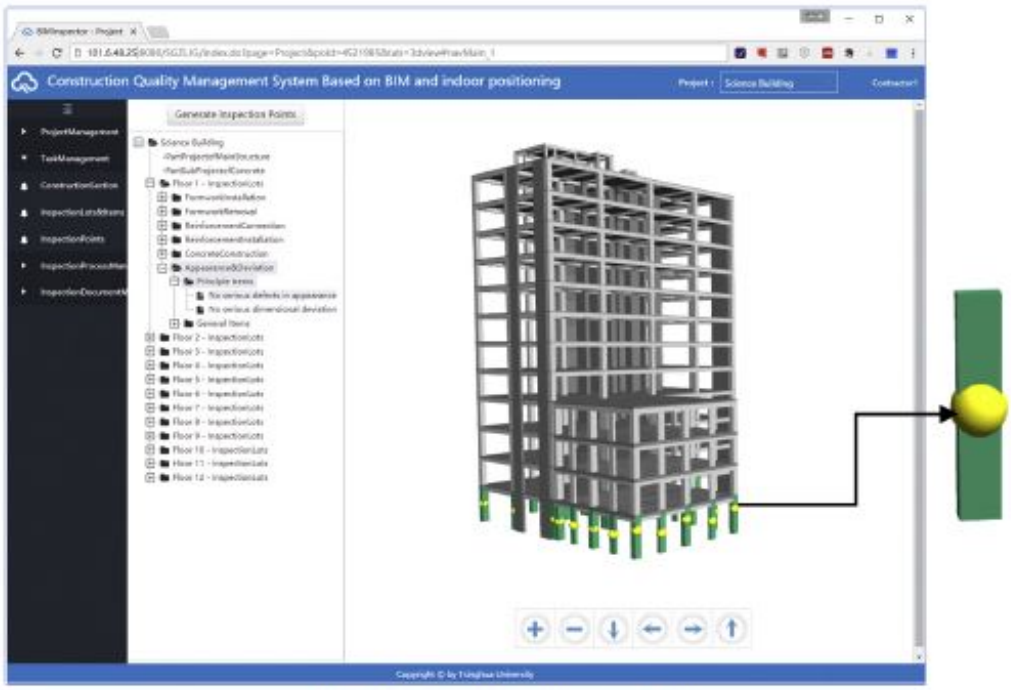


Figure 4. BIM model of a building construction. (Ma et al, 2018, p 40)

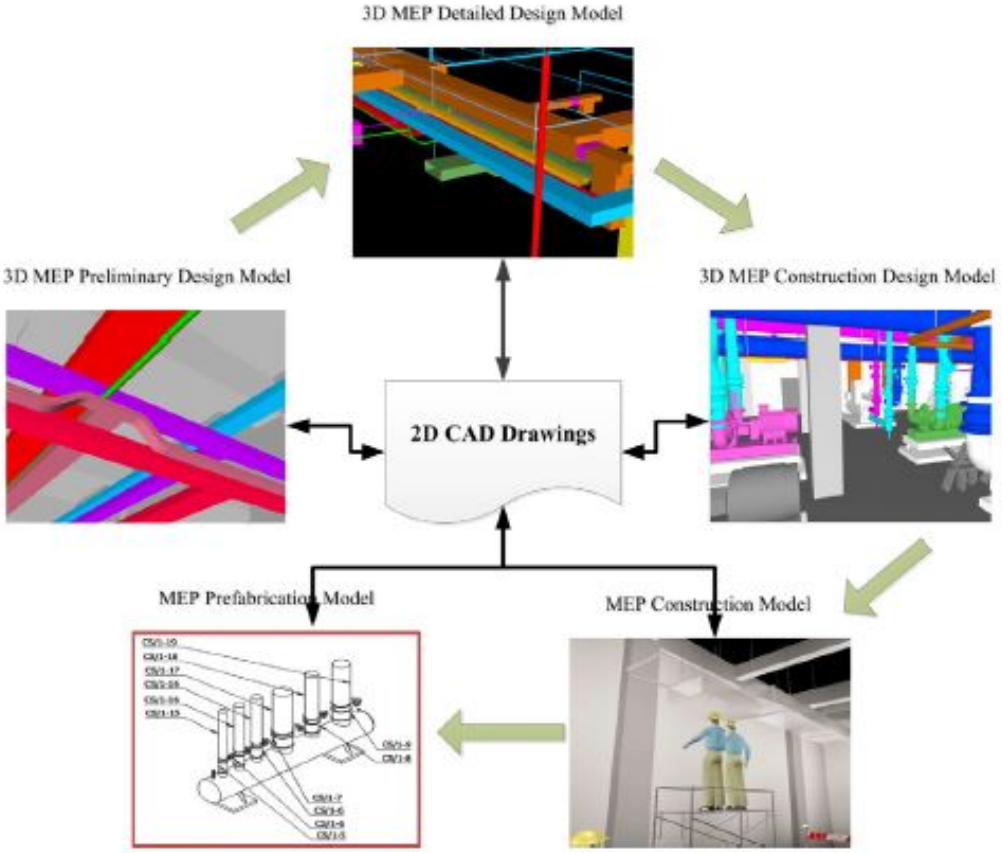


Figure 5. Representation of a MEP design BIM process. (Wang et al, 2016, p 139)

Although many benefits of BIM are elaborated in the literature, there are still improvements for the further implementation of this tool. Merschbrock & Munkvold (2015) state that BIM and other digital innovations can change the design and construction sector to a large extent by means of increasing integration, transparency and productivity, which can lead to cost savings and a higher product quality. However, in practice, this potential is not always met, because construction teams often find working with these new technologies difficult, due to the fact that BIM changes routines in ways of working (Merschbrock & Munkvold, 2015).

Complex hospital projects

Most healthcare projects can be seen as complex projects (Bakshi, Ireland & Gorod, 2015). Healthcare projects are more complicated and rigorous compared to other building designs (Huang, Yien, Chen, Su & Lin, 2017). Due to the complexity involved, healthcare projects have the "opportunity to harness the strengths of BIM'' (Merschbrock & Munkvold, 2015, p3).

According to Bakshi et al. (2015), complex projects can include the following characteristics: they are non-linear, interdependent, there are unique local conditions, they are uncertain and ambiguous, and the boundaries are unfixed. Complex projects can be divided in seven complexity aspects: context, autonomy, belonging, connectivity, diversity, emergence and size (Bakshi et al, 2015). These aspects are shown in figure 6 below.

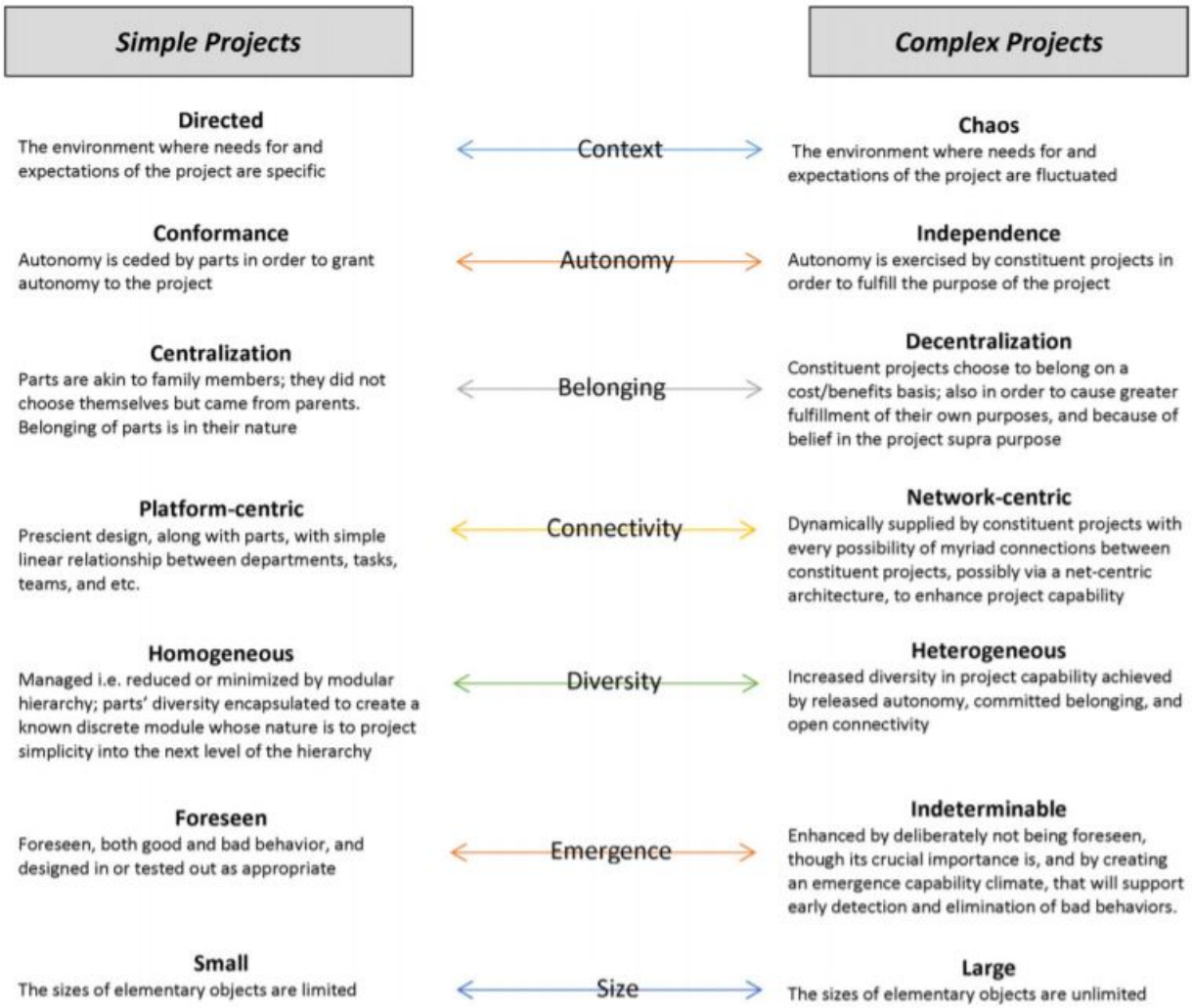


Fig. 8. Project complexity drivers and their paradox synthesised from Boardman and Sauser (2006), Cicmil (1997), and Vidal et al. (2011a).

Figure 6. Simple versus complex projects. (Bakshi, Ireland & Gorod, 2015, p 1206)

According to Remmington and Pollak (2007) the complexity influences the project and its life cycle, including the time required for the different project phases. Its complexity has an effect on the moments of critical reviewing, the type of governance, the way the project is procured and the management of the contract. It further affects the budget and schedule, the choice of key recourses, and the way that risks are managed. All projects involve some types of complexity. .

Remmington and Pollak (2007) describe four types of complexity: technical, directional, structural and temporal. The bigger the project, the more chance that all complexity factors are present. Although, not all parts of the project necessarily contain all kinds of complexity.
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Structural complexity: goes together with being less or more familiar with a project type, although the line between "simply" complicated and complex can be unclear. Structural complexity is connected to large engineering, construction and defence projects. Managing

these projects comes down to dividing outcomes into small deliverables. In these projects, major challenges are scheduling, organization, contract management and interdependencies. .

Technical complexity: this type of complexity is present in projects where new products are involved, or techniques that have not been used in previous projects. In this case, the complexity is connected between various interdependent solutions. This type can be found in engineering, industrial design, architecture, IT and R&D projects in the pharmaceutical and chemical sector. It is connected to managing stakeholders expectations, managing the critical design phases and contracts, and creating solutions for technical and design problems.

Directional complexity: exists in projects where goals and paths are not shared, meanings are unclear or hidden agendas exist, caused by varying ideas on goals and objectives. To cope with this, it is important to take time to create project definitions which enhance shared meaning, as well as to manage organisational politics and relationships between actors. For a successful project, sense of culture and awareness of politics are key.

Temporal complexity: is related to changing strategy and external and environmental factors, uncertain constraints in the future, and expectance of change, as well as the existence of the project in the future, which is mostly outside of the project team's control. This type of complexity occurs in long run projects, where e.g. external factors cause delays, which is possible in each phase of the project life cycle (Remington & Pollak, 2007).

Communication and collaboration with BIM

There are various ways of communicating and collaborating with BIM. To prepare this collaboration, BIM objectives can be shared through e.g. guidelines and protocols, secondly, actors can work together online in a shared environment, and using virtual reality to show 3D images to clients or end users (Cavka, Straub & Pourier, 2017; Merschbrock & Munkvold, 2015; Merschbrock Lassen, Tollness & Munkvold, 2016). Communication of BIM requirements and project outcome can be done via BIM standards, BIM policy, BIM guidelines, BIM protocols or BIM execution plans. The difference between e.g. standards and protocols is that: standards state the required outcome of the project, and protocols include information about how to achieve this outcome (Cavka et al, 2017). A recent view on BIM is that of a 'boundary object': a virtual, physical or electronic object, which carries information. Different actors can have different interpretations of boundary objects, which creates the need for someone that creates shared meaning. This person can also be called a boundary broker or boundary spanner. The boundary broker is a person who can mediate in projects due to the fact that other actors have much trust in him/her, and who translates the meaning of the boundary object amongst the others. (Papadonikolaki & Van Oel, 2018)

Two possible processes of how various actors can work together in BIM are shown in figure 7 and 8.

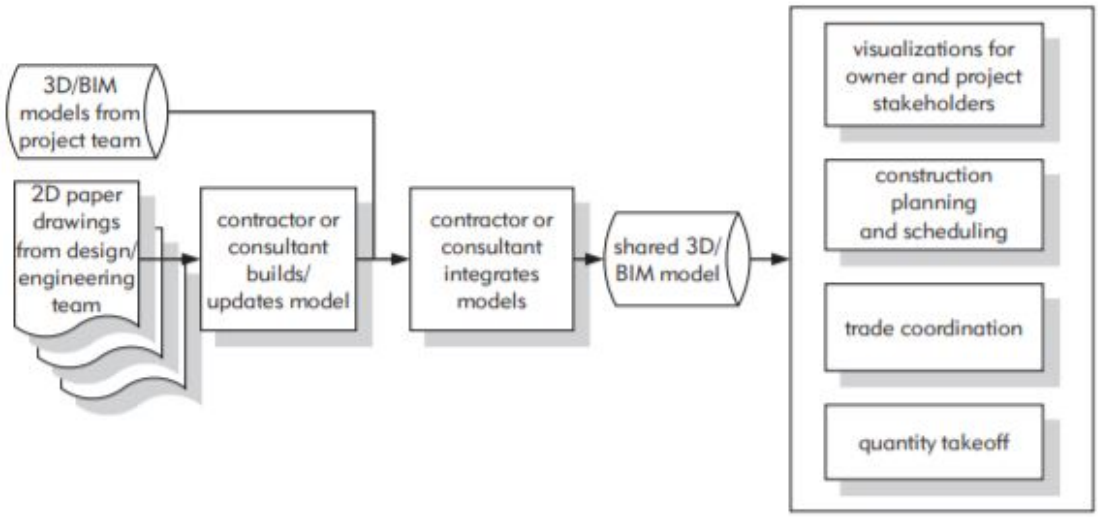


Figure 7. BIM process in which different actors use 3D modelling tools to form a shared 3D model. (Eastman, 2008, p 215)

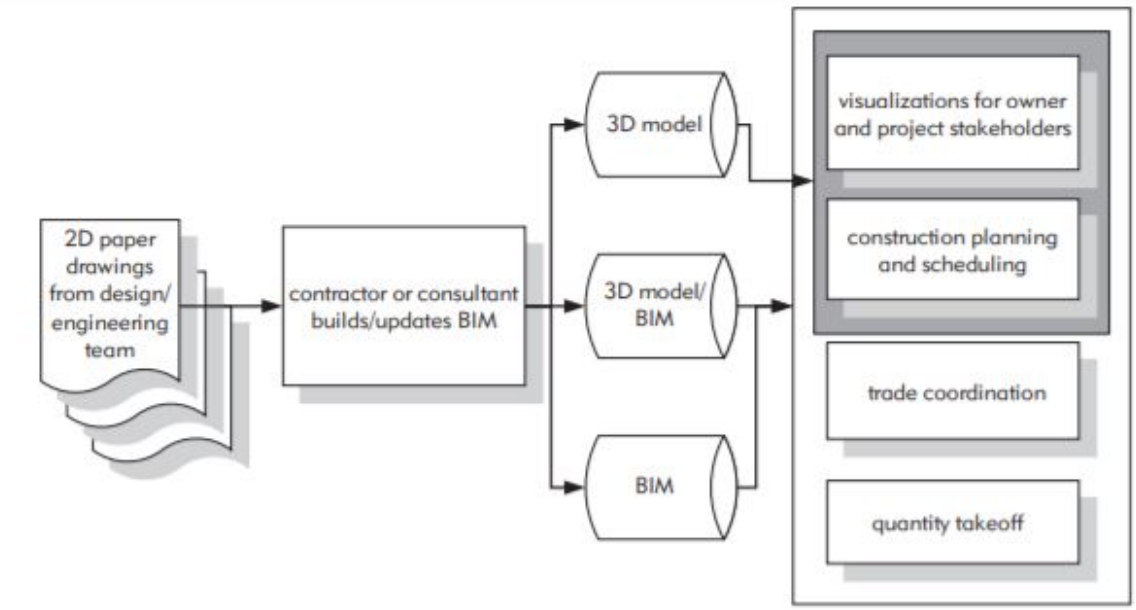


Figure 8. BIM process in which the contractor builds a 3D model from plain drawings for quantity take-off, planning and clash detection. (Eastman, 2008, p 216)

Different ways of communicating and collaborating in BIM can be e.g. via an open BIM environment such as Industry Foundation Classes (IFC), a free and open format which is not bound to a specific BIM software, so that different types of BIM software can be used to share and/or exchange information. IFC can be used for the whole life cycle of a building: from testing the feasibility of the project, to design, construction, and use (Andriamamonjy, Klein & Saelens, 2016; Martinez, Tisi & Douence, 2015).

Working and designing together in an online environment, “in the cloud”, is also possible, for example with the programs: “BIM360” and “Collaboration for Revit” from Autodesk. Designing together in a shared environment makes it possible to verify information, identify inconsistencies and create point for action (Akponeware & Adamu, 2017).

BIM can be used to resolve design errors, or “clashes”. Below in figure 9 and 10, examples of clashes and clash coordination are shown. Figure 9 shows an example of removing clashes, figure 10 shows how the design can be optimized. Table 1 shows possible reasons of these clashes.

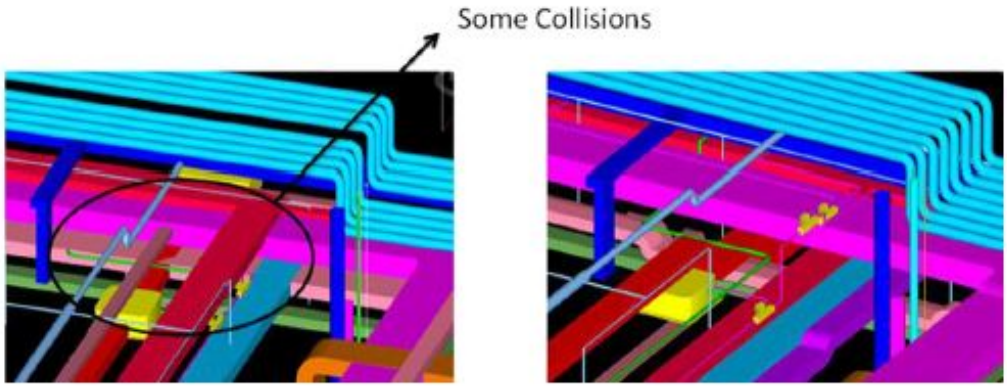


Figure 9. Resolution of a clash. (Wang et al, p 141)

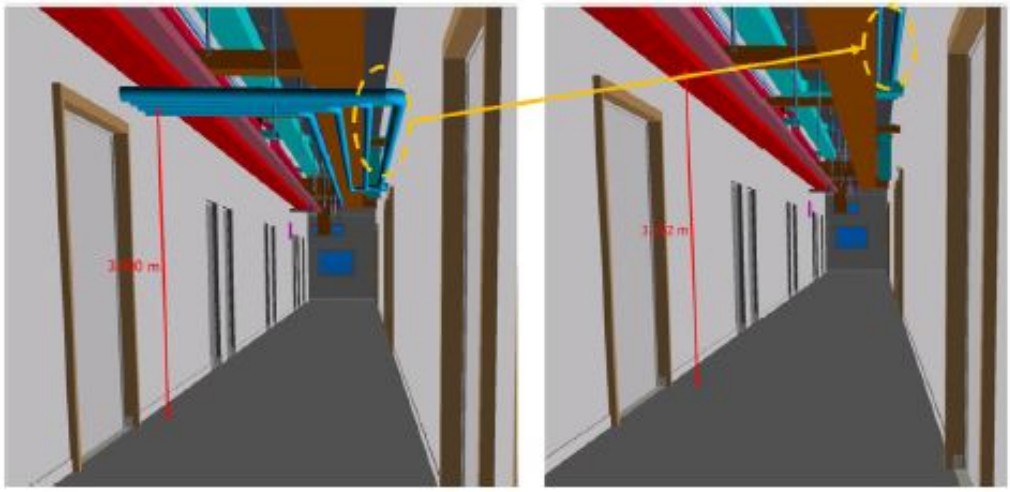


Figure 10. Design optimization after clash coordination. (Wang et al, 2016, p 141)

The following table shows the main causes of clashes in building design.

Cause of Clashes	**Authors that mentioned clash**
Use of wrong or low level of detail	[4]: (Leite, F., Akcamete, A., Akinci, B., Atasoy,G. & Kiziltas,S., 2011)
Design uncertainty/use of Placeholders	[21]: (Tommelein, I.D. & Gholami, S., 2012)
Failing of design rules	[21]: (Tommelein,I.D. & Gholami,S., 2012)
Accuracy versus deadline	[21]: (Tommelein,I.D. & Gholami,S., 2012)
3D model objects exceeding allowable clearance	[21]: (Tommelein,I.D. & Gholami,S., 2012)
Designers working in isolation from each other	[25]: (Craig, D.L.; Zimring, C., 2002) [36]: (Kalay, Y.E., 1998) [37]: (Froese, T.M., 2010)
Design complexity	[21]: (Tommelein,I.D. & Gholami,S., 2012), [31]: (Korman, T. & Simonian, L., 2010) , [38]: (Ashcraft, H.W., 2008)
Insufficient time	[29]: (Benning, P.; Dumoulin, C.; Dehlin, S.; Tulke, J.; Åberg, P.; Fristedt, S.; Holopainen, R., 2010), [38]: (Ashcraft, H.W., 2008)
Use of 2D instead of 3D models	[4]: (Leite et al. 2011) [24]: (Hartmann, T., 2010) [39]: (Shafiq, M.T.; Matthews, J. & Lockley, S.R., 2012)
Design errors	[13]: (Love, P.E.D.; Edwards, D.J.; Smith, J.; Walker, D.H.T. , 2009) [21]: (Tommelein,I.D. & Gholami,S., 2012) [40]: Han, S.; Love, P.; Peña-Mora, F., 2013)
Use of different file formats	[41]: (Kensek, K.& Noble, D, 2014).
Lack of experts	[4]: Leite, F., Akcamete, A., Akinci, B., Atasoy,G.; Kiziltas,S., 2011) [38]: (Ashcraft, H.W., 2008), [41]: (Kensek, K.& Noble, D, 2014) [42]: Leon, M.; Laing, R., 2012) [43]: (Leite, F., 2015) [44]: (Wang, L.; Leite, F., 2014)

Table 1. Causes of clashes in building design. (Adjusted by including authors of the , from: Akponeware & Adamu, 2017, p4)

BIM can be used to facilitate the interaction between different stakeholders. However, when BIM does not facilitate easy interaction and realistic visualisations, it is difficult for the participating actors to understand and imagine the design, and consequently to advise the designers, or provide feedback in the form of professional medical requirements.

BIM can also be integrated with gaming, by means of e.g. three dimensional walkthroughs, as well to collaborate virtually, to educate and train people, to design, plan and simulate *(*Merschbrock et al, 2016). To cope with the communication gap between different actors, and to improve interactive performance and visualisation, for example an interactive visualisation system can be used. This system integrates a game engine with virtual reality in BIM, together with professional requirements for healthcare. The system shows the spatial design, architecture and building information. Also, users can use a wireless gamepad for interaction with the BIM model. A pilot showed that the system was useful. However, costs of the system may be a negative aspect for adoption of the system (Huang, Yien, Chen, Su & Lin, 2017). It is also proposed by Kalfan, Khan & Maqsood (2015)

that education by gaming and visualization can be integrated with BIM to facilitate a way for designers to make simulations of user activities (Kalfan, Khan & Maqsood, 2015). .

Actors roles and competences

Due to BIM, actors need different skills and competences, and consequently, new roles emerge. To be able to communicate, collaborate, negotiate, work in a team with BIM and manage conflicts, actors need a set of personal competences which involve “a combination of personality, experience, and training or education” (Papadonikolaki & Van Oel, 2016, p95). Further, BIM implementation depends on the readiness of involved actors in the project, as well as how capable they are with BIM (Papadonikolaki & Van Oel, 2016).

Roles that emerge to the implementation of BIM are e.g.: e.g. BIM manager and model manager, BIM project manager, BIM director, BIM coordinator, BIM designer, senior architect, BIM MEP coordinator, and BIM technician (Uhm, Lee & Jeon, 2017; Sebastian, 2011). Figure 11 gives a representation of possible BIM jobs. Table 2 gives an overview of existing BIM roles and related competences.

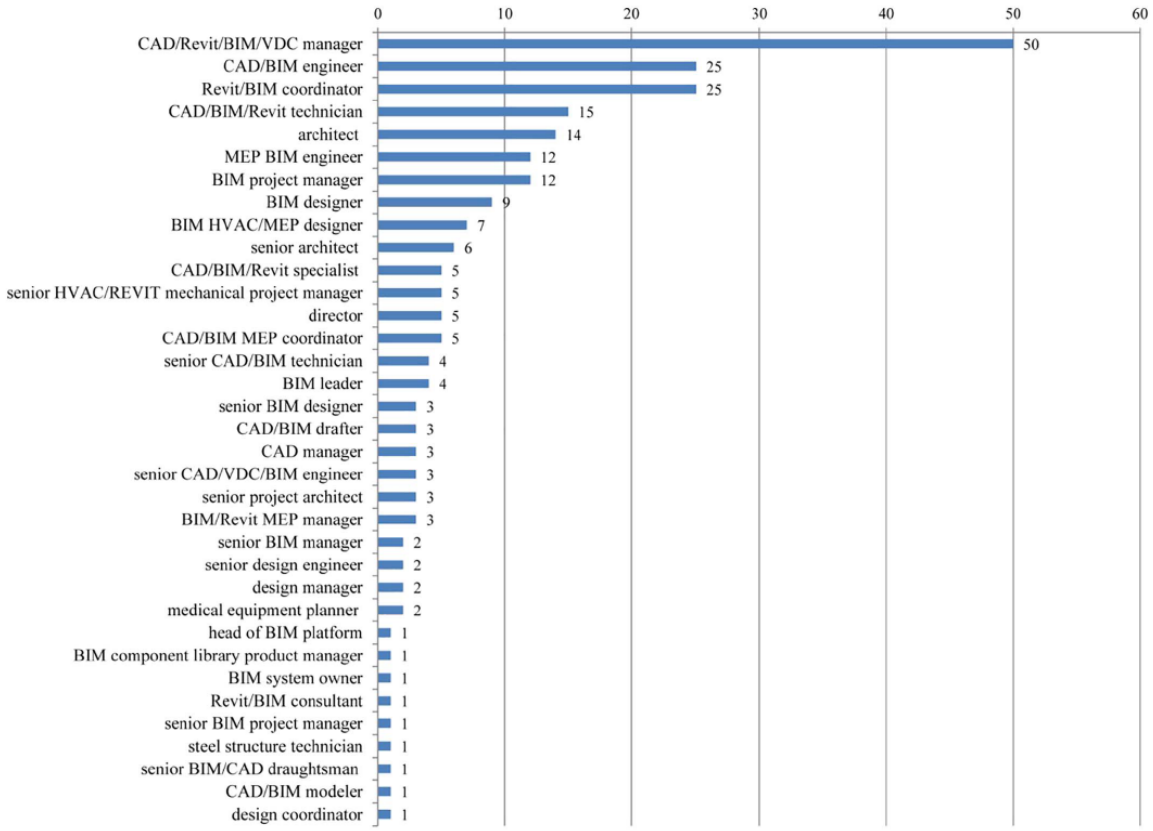


Figure 11. Possible BIM roles. (Uhm et al., 2017, p 71)

	O*NET elements	BIM project manager	Director	BIM coordinator	Senior architect	BIM manager	BIM designer	BIM MEP coordinator	BIM technician
Work style	Initiative							▲	
	Leadership		▲					▲	
	Cooperation		●	●	●	●	●	●	●
Basic skills	Writing			▲	▲				
	Speaking	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙
	Technology design			▲		▲			
	Quality control analysis			▲					
	Time management							▲	▲
	Management of personnel resources	▲							
Knowledge	Computers/electronics		▲	▲					
	Engineering/technology	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙
	Design		●	●	●	●	●	●	●
	Building/construction						▲	▲	
	Mechanical							▲	
	English language	▲			▲				
	Foreign language	▲	▲						
	Law/government	▲				▲		▲	
Education	Technical vocational	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙
Experience	BIM–related work experience	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙
Licensing	License or registration required	▲	▲					▲	
	Post–secondary degree	●	●	●		●	●	●	●
	Graduate degree	▲							
Generalized work activities	Evaluating information to determine compliance with standards		●	●	●	●		●	●
	Making solving problems				▲				
	Thinking creatively		●	●	●	●	●	●	●
	Scheduling work and activities		▲					▲	
	Organizing, planning, and prioritizing work			▲					
	Interacting with computers	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙
	Drafting, laying out, specifying technical device, equipment		●	●	●	●	●	●	●
	Documenting/recording			●	●	●		●	●
	Communicating with supervisors, peers		●	●		●		●	●
	Establishing, maintaining interpersonal relationships	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙
	Coordinating the work and activities of others	▲					▲		▲
	Training and teaching others			▲		▲		▲	
	Guiding, directing, and motivating subordinates	●	●	●		●		●	
	Provide consultation and advice		●	●	●	●	●	●	
	Performing administrative activities			▲			▲	▲	
Organizational context	Have control over unit or department		▲						
	Monitor data on quality/costs/waste/etc.		●	●	●	●	●	●	●
	Determine workflow or order of tasks		▲			▲			
	Develop new products, services, and procedures		▲						
	Opportunity for independence and freedom		▲						
	Providing high–quality products							▲	

* Sign "⊙" indicates essential competency, "●" common competency, and "▲" job–specific competency.

Table 2: BIM roles and common, essential and job-specific competences (Uhm et al., 2017, p77)

Sebastian (2011) mentions the new role of "model manager" who focusses on:

- "the development of BIM, the definition of the structure and detail level of the model, and the deployment of relevant BIM tools, such as for models checking, merging, and clash detections;
- the contribution to collaboration methods, especially decision making and communication protocols, task planning, and risk management; and
- the management of information, in terms of data flow and storage, identification of communication errors, and decision or process (re-tracking)" (Sebastian, 2011, p 181).

Khalfan, Khan and Maqsood (2015) state that an important task of the BIM manager is to set up a project database and regulate the flow of information between the teams, while taking into account the entire project life cycle (Khalfan, Khan and Maqsood, 2015).

There is not always conformity between the expected roles and expertises of team members about their own roles, compared to expectations other actors have about the roles and expertises of members of their team (Papadonikolaki & Van Oel, 2016). Table 3 below shows these differences.

Actor	Perception of own role	Expectations from other actors
Architect	BIM technical skills, seeking consensus, and engaging in informal communications	Domain-related expertise and engaging in early discussions
Structural Engineer	BIM technical skills, coordination, domain-related expertise and engaging in informal communications	Ensuring long-term relations
MEP Engineers	Domain-related expertise and showing respect	Engaging in informal communications
Contractor	Engaging in early discussions, meeting the formal agreements, coordination, and BIM technical skills	Domain-related expertise and ensuring long-term relations
Sub-contractor	Domain-related expertise and engaging in informal communications	BIM technical skills and ensuring long-term relations
Supplier(s)	Meeting the formal agreements and engaging in informal communications	BIM technical skills, discipline-related expertise, and coordination
Client	N/A	Engaging in early discussions and informal communications
Multi-actors	N/A	Communication across all tiers, seeking consensus and displaying joint responsibility

Table 3. Occurrences of the perceptions and expectations of various actor's BIM roles. (Papadonikolaki & Van Oel, 2016, p99)

Communication with BIM in hospitals: project phases and project stakeholders

In the lifecycle of a building, many actors, interfaces and knowledge are involved. The extensive length of this lifecycle makes that integration and communication have importance for a long period long time. In the design phase, it is determined how practical and usable the building is (Huang, Yien, Chen, Su & Lin, 2017). During the operation phase, which is the longest phase of the life cycle, interaction exist between professionals, stakeholders, facilities and management activities. It also involves space planning, scheduling, repairing and emergency managing (Peng, Lin, Zhang, & Hu, 2017).

Communication between stakeholders

A well-considered and suitable design can lead to reduced costs and improved efficiency in the operation phase, e.g. by the placement of departments and wayfinding. Thus a good communication about requirements during the design is very important, especially for complex buildings such as health care (Huang, Yien, Chen, Su & Lin, 2017). However, it can be difficult for the architects to understand all the medical requirements and for the medical practitioners, when shown complex drawings it can be difficult for them to understand the spatial design and its suitability for medical practice. Insufficient communication amongst stakeholders can lead to an end product that is does not meet the requirements of the hospital board and the care professionals (Merschbrock & Munkvold, 2015).

Merschbrock & Munkvold (2015) described the involvement of end users of a hospital building by means of serious gaming. Various perspectives of different stakeholders were taken into account. The actors that participated in the project were a person responsible for BIM, someone responsible for the game, four game developers, a healthcare expert and five healthcare professionals who tested the game. The game helped medical professionals to relocate to a new healthcare building. The aim of this game is to enhance teamwork and communicating between the different stakeholders, in order to let the building be satisfactory for future users (Merschbrock & Munkvold, 2015).

Data exchange between phases

BIM can further be used to exchange information from the design and construction phase to the operation and maintenance phase. These big amounts of data can be managed by BIM platforms to improve interoperability, for better facility management. Some challenges or improvements considering this use of BIM are the large amount of data that has to be processed, as well as the fact that managers need professional knowledge to access the information. Also, inaccurate data, e.g. through erroneous manual input, possibly hampers management. Because manual checks are nearly impossible, Peng, Lin, Zhang & Hu (2017) propose algorithms for data management, which provide the opportunity to extract data from the design and construction phase, and to share this information between stakeholders in a shared platform. They discuss improvement of their system: a further optimization of the algorithms, integration of Internet of Things, and professional training of e.g. data analysts with AEC knowledge. Furthermore, discipline and accuracy in databases should be improved and missing data should be reduced to optimize the platform (Peng, Lin, Zhang & Hu, 2017).

Validation and verification of the design/model

To get a well-functioning model (or design), it has to be validated and verified. Validation means that the model is satisfactory accurate with its domain of application, verification refers to the fact that the (computer) programme or model is correct and correctly implemented. Connected to these concept is the credibility of the model (Sargent, 2013

According to Eastman (2008) verification of the design and BIM should be done in order to know that the intention of the design did not change. When the design develops, things are added and changed on the way, and thus the following verification is needed:

1. The verification of the substitution of different parts of the design, and their interconnectedness

2. The consistency of the placement and geometry of objects, in connection to the other objects (Eastman, 2008, p 189, 190).

Different design review processes can exist. Figure 12 shows the review process of a traditional design process, figure 13 shows the review process of a BIM based design process.

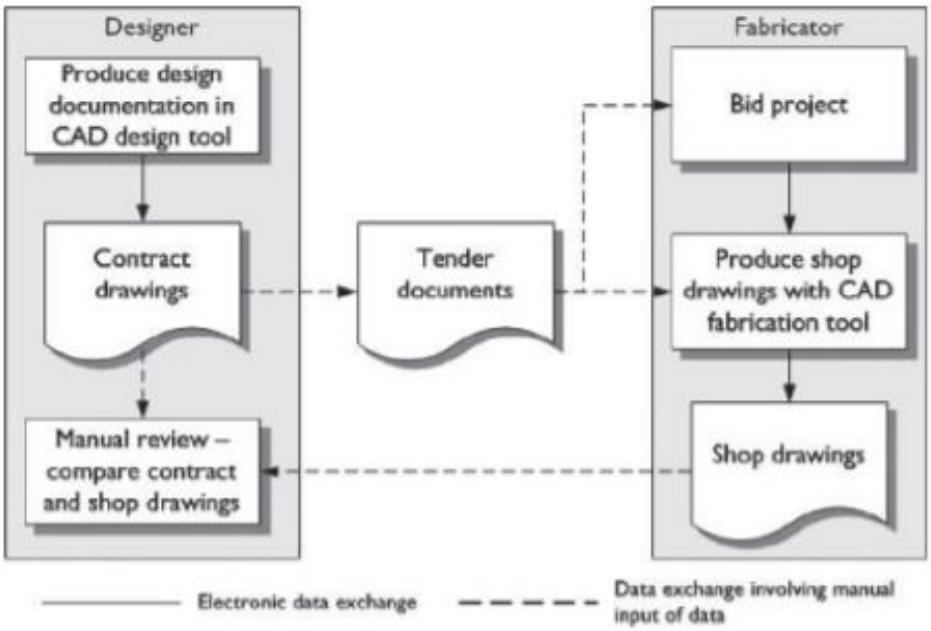


Figure 12. Traditional design review process, with 2D cad drawings. (Eastman, 2008, p189)

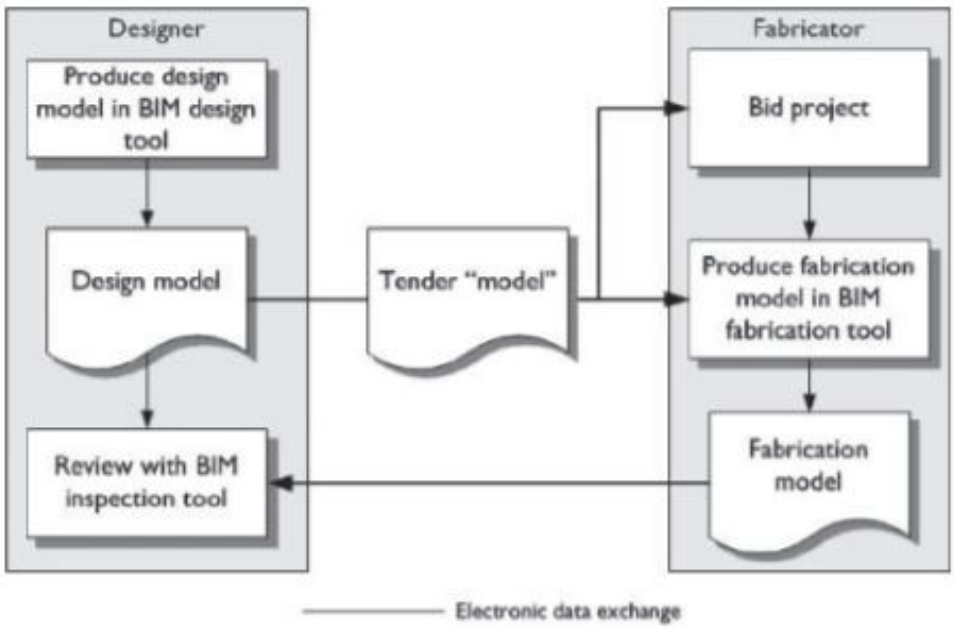


Figure 13. BIM based design review process. (Eastman, 2008, p190)

Research gap

Although much literature is available on the different aspects as shown above, little research is done on the specific subject of how the design of hospitals is validated and verified between the various stakeholders, while they are working with BIM. Considering the communication gap between different actors and the beforementioned benefits of good

communication in the design phase for the use phase, (Huang et al, 2017; Peng et al, 2017), more research is required on how actors communicate with each other during these phases, while making use of BIM.

Conceptual model

The different findings from literature lead to a conceptual model for further research in the empirical part, as shown in figure 14 below.

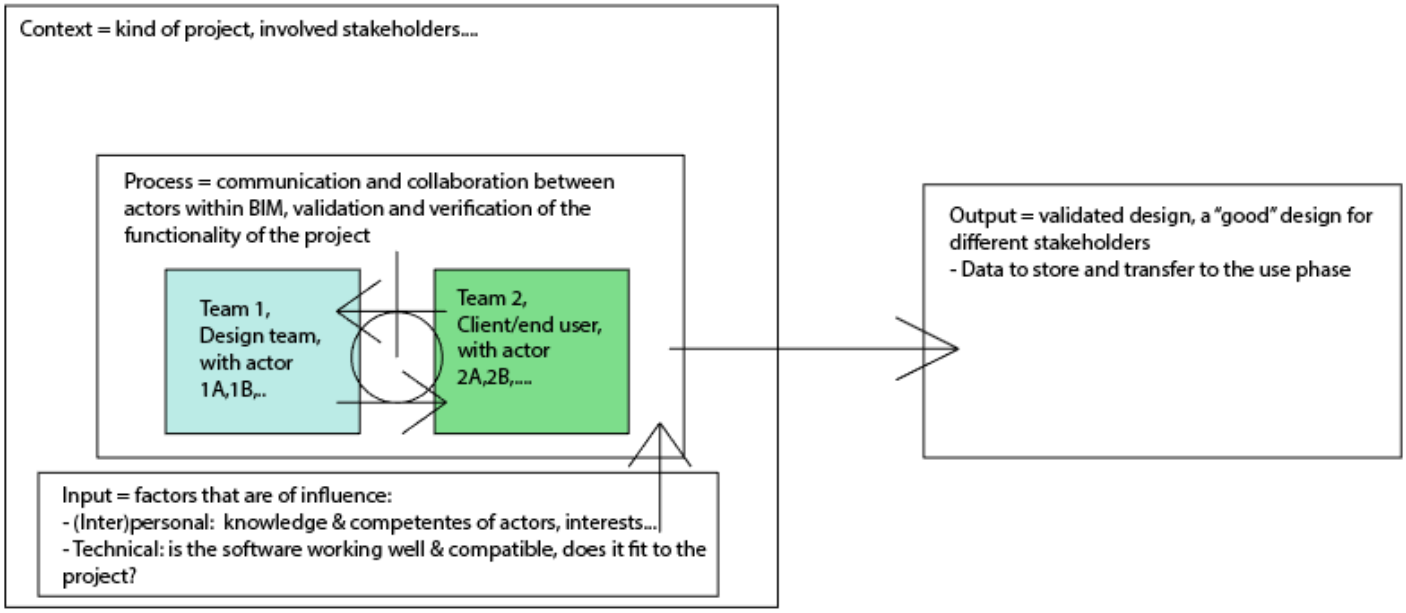


Figure 14. Conceptual model of the Research.

In the conceptual model the Input-Process-Output (IPO) model is used as a basis. It is stated by Hosseini, Bosch-Sijtsema, Arashpour, Chileshe and Merschbrock (2018), that the IPO model is often used to study (virtual) team effectiveness. In the IPO model, inputs are part of the project composition, team structure, and complexity of the organisation. Processes involve how team members interact, as well as what they need for fulfilling their tasks. Output refers to the expected results of the team(s). (Hosseini et al, 2018)

To form the conceptual model, the context of the project is included in the IPO model, because in previous interviews with different project actors it became clear that project context can be of major influence. The context involves amongst others: what kind of project is it, which actors are involved, and how these influence the collaboration between the different actors with BIM.

Second, the input part of the model shows the factors that influence the communication and collaboration between stakeholders, such as interpersonal and technical factors. Interpersonal factors can be as beforementioned, knowledge and competence of actors considering BIM, or e.g. communicative skills, and technical factors can be the usability of the BIM software.

Third, the process involves the communication between the different actors, which is facilitated by BIM as a tool. The actors involved in the design team, and the client/end-user of the project may differ per project. Questions related to this part are: is there a well-functioning communication between the various actors? And how is the functionality of the project validated and verified?

The fourth part of the model is the output of the process. This output involves the validated and verified design, including design decisions, and which data is stored and transferred to the use phase. Questions that arise are: how do the different actors evaluate the design? Are the design, BIM model and process according their wishes?

3. Research methodology

Relevance and aim of the research

The relevance of this research lies in the fact that it is stressed in literature and the first interviews held, that the communication with BIM is still a critical aspect in complex projects such as hospitals. Multiple interviewees stated that BIM does not work in practice as is proposed from literature and BIM program makers. First, there is often a lack of well-functioning communication between actors working with BIM, second, involved actors do not always have the required BIM related skills, and third, the connection between the design phase and the use of these complex buildings is mentioned as critical by practitioners: in terms of including the use requirements in BIM during the design phase, and the readiness of the BIM model for the use phase.

Therefore the aim of the research is to get a better insight in - and if possible to improve – the processes of communication and collaboration with BIM in the design and use phase of hospital buildings: more specifically insight into validating and verifying the design and corresponding BIM model for the use phase, between different project stakeholders.

Methodological rationale

In this part, the research method, and the reasons to choose this method, are given. First the research questions are stated, after this, the research method is elaborated.

Research questions

The main research question is:

In what way are the **functionality of the design of hospital buildings, and the suitability of the corresponding BIM model** for the **use (phase), validated and verified** between the **various stakeholders,** while they (may or may not) use **BIM**, and what are the **critical points** for a **successful process**?

The corresponding **sub questions** are:

1) *To what extent, and in which way is BIM used in the design phase of hospital buildings as a means to share information about the hospital between the design team and the client/end-users of the hospital?*
2) *To which extent is there a well-functioning communication/information sharing between the actors within BIM (e.g. due to their competences) and a well-functioning BIM model (e.g. compatibility and interoperability)?*
3) *How are the design and BIM model validated and verified between the project team and the client/end-user, and how is BIM used in this process?*
4) *In which way does the use of BIM influence the collaboration and work process (positive/negative)?*

5) *To what extent is the BIM ready for use by the client during the operation phase (functional process), and maintenance?*

Research method

The research is based on grounded theory and sensitizing concepts. Grounded theory is a research method in which a cyclical way of collecting and analyzing data is used. Sensitizing concepts are starting points that give direction to further research. (Bowen, 2006)

In this research, first, a literature analysis and primary interviews and observations were held to define sensitizing concepts on which the main research question and sub questions were formed. The first sensitizing concepts based on these interviews were: *BIM and communication with BIM, complex projects, changing roles and competences of actors (due to BIM), clearness and ambiguity (of BIM objectives), team communication and collaboration, process and outcome, involvement of end users, and critical success factors*. On this concepts, further research was done, which lead to the main research question and sub questions, and consequently the main topics for interviews and observations, as shown in the results section of this report. For confidentiality reasons, the full interviews are not included in this report. A structured table of the main findings and corresponding quotes can be found in appendix C. For the main part of the research, the following project partners of two cases were interviewed:

Dutch case	**Foreign case**
Client:	Foreign party 1:
1. BIM director	1. BIM manager
2. Project manager	Dutch subcontractor:
3. Central information manager	2. Project manager
Main contractor:	3. BIM coordinator MEP
4. BIM director	4. BIM coordinator architecture
5. Planner	5. BIM modeler

In grounded theory, categories that are found in the data can be categorized by means of coding. By coding the interviews, it can be counted how often concepts are present, and more importantly, different parts of interviews in which the same codes are mentioned can be grouped and analyzed as a whole. (Byrant & Charmaz, 2007) In this research, coding was done in Atlas TI, to count and group the codes, as well as to find co-occurrence connections between different codes, connected to the sub research questions. The coding results are elaborated in the results part of this report. The full analysis of codes, their density, and relevant co-occurrence of codes can be found in Appendix D. An example can be found in the case study protocol.

This study was formally approved by the Human Research Ethics Committee of Delft University of Technology (HREC). Following the ethical guidelines of the HREC, informed written consent was obtained from each informant, anonymity was assured and informants

were informed that they could withdraw from the interview and/or observations at any time. The data were treated with confidentiality.

Case study protocol

Due to the fact that not much literature is available on the specific subject of research, it was chosen to conduct observations and interviews of two cases. Case study research makes it possible to understand practice-based problems more in-depth, and takes into account the importance of context. (Benbasat *et al.*, 1987; Orlikowski and Baroudi, 1991; Yin, 2009, in Merschbrock, Lassen, Tollnes & Munkvold, 2016, p 793).

According to Yazan (2015) there are multiple ways to conduct case studies. From a very open view as used by Stake, to a very structured view as used by Yin, and a mix of both as used by Merriam.

In this research, a structured research proposal was used, by means of predefined research questions and observation criteria. However, during the observations and interviews, an open view was kept to take into account important things that were not originally in the predesigned codes. In the interviews, things that came up during the observation where asked to be elaborated in more detail. The observation and interview criteria are stated below:

Observations

Following the literature and exploratory interviews, the following observation topics were extracted:

- Who attend the meeting, what is the goal of the session? *(context)*
  - Which actors of the design team and client/end users involved? *(context)*
- In what way is BIM used and communicated with? (What goes (not so) well?)
- How is the design validated and verified between the stakeholders? (e.g. design decisions made)
- What is done with the design decisions and data corresponding to BIM?
- (How is the meeting managed?)

The observation topics lead to the following codes to mark during the observation:

- **BIM definition:** how do the actors define BIM?
- **Knowledge sharing:** Boundary object, boundary broker
- BIM as **Communication tool:** what kind of tool is the BIM, and how is it used?
- **Validation/Verification** of the design
- **Competences** of actors: do they influence the communication?
- **Design team** (D), **Client** (C) or hospital (management), **End users** (E)**:** staff, partnerships etc.
- **Rest:** important things that are different from before mentioned codes

Interviews

After the observations, in depth interviews were held to explore the topics according to the predesigned topics and expertise of different actors. The interviews lasted around an hour, depending on the interviewee's time and given information. The main interview topics were the following:

1. Use of BIM in the project (what, how and why)
2. Communication/information exchange
3. Validation and verification of the design/BIM model
4. Actors competences
5. Collaboration and work process
6. Management
7. Involvement of the client/end users
8. Readiness of the BIM model for use and maintenance

The full interview can be found in appendix B.

Coding

To analyze the interviews, coding was done in Atlas TI. Hereafter, co-occurrence was done for each research questions between relevant codes, to draw conclusions about connections between the different subjects. The following table shows an example of the co-occurrence for research question 2 in the Foreign case, between the code topics information exchange & communication and critical factors. The full analysis can be found in appendix D.

Co-occurrence between information exchange and communication (D&G) vs Critical Factors (J)

	J1	J2	J3	J4	J5	J6	J7	J8
D1	7	7	12	14	4	3	1	1
D2	1	2	4	3		1	1	
D3			1					
G1	7	12	10	4	1	4		3
G2								
G3								

(→ Table D.6.11.) Codes most mentioned together: Information/Data structuring (D1) vs Negative aspect/possible improvement (J3) and Transition (J4), and communication (G1) vs Positive aspect (J2) and negative aspect (J3).

Case selection

The research involved two hospital cases, one in the Netherlands, and one Foreign case. The former was investigated at the end of the design process (final design-delivery for construction), by means of interviews, in which also one was combined with an observation of a BIM model *(Interview with BIM manager)*, to reflect on the process during the design. The latter was observed a bit earlier in the process, during the technical design phase, to investigate the communication between stakeholders who work with BIM during the design phase. This was done by means of project meeting observations, and interviews including one with an observation of the BIM model *(Interview with BIM modeler)*. Below, the case contexts are described.

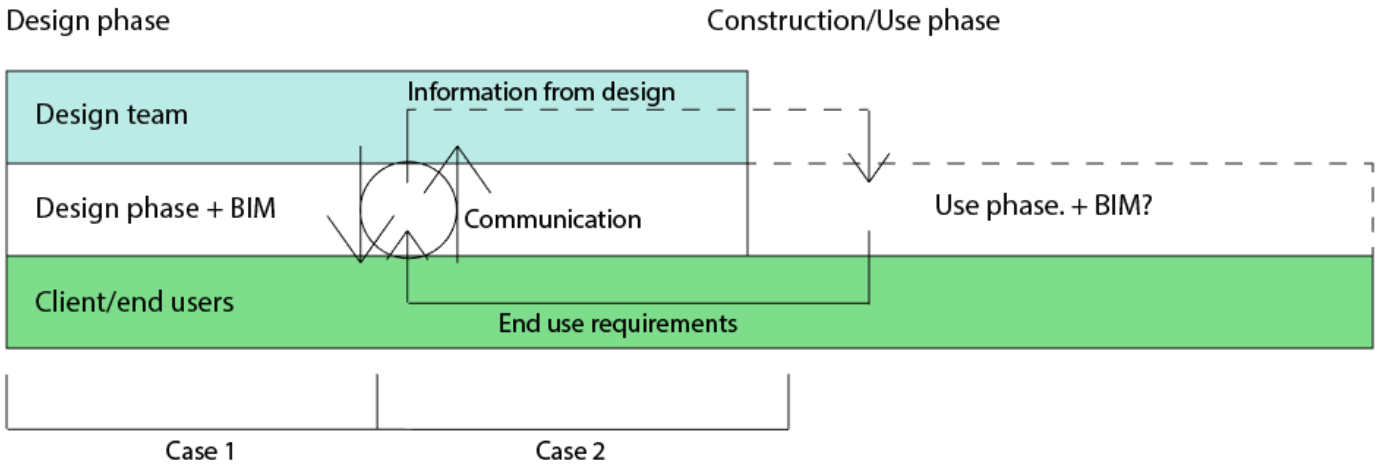


Figure 15. Schematic overview of the case study research.

Case context: Dutch Hospital case

Organization of the project - Contract form, project partners and their responsibilities

The project is a public procurement project. The project organization is an existing hospital somewhere in the Netherlands, which offers a broad range of medical care. (Project manager Dutch case, personal communication, April 10, 2018; Interview)

The organization is looking towards a more integrated way of working. For construction, the hospital works together with actors such as: architects, advisors (e.g. installation advisors), construction engineers, suppliers of e.g. installations. They also consult end-users (staff) in the design process. (Central information manager, personal communication, November 10, 2017)

This specific project involves a renovation of a division of the hospital, which is explored in the project phase of TO (Technical Design), to delivery for construction (Uitvoerings Ontwerp/Effectuation Design). Table 4 shows the the different project partners and their responsibilities. The contractual relationships in the project can be found in appendix A.1.1.

Project partners in the project	**BIM Responsibilities**
Client (Hospital)	BIM manager checks models
Architecture	Architecture model: Revit 2016, Navisworks
Construction	Construction model – was implemented in Architecture model
Advisor E+W	Model E installations: Revit 2016
Main contractor	Work out design in 3D and combine models -> IFC/solibri > Subcontracted Architectural finishing architect for this
Installator E+W	Model E&W Installations: Revit 2016
Architectural finishing	Worked out design in 3D: Revit

Table 4. Project partners and BIM responsibilities. (Translated and anonymized from BIM uitvoeringsplan, 2017, p 6&7; BIM manager, personal communication, April 10, 2018; Project manager personal communication, April 10, 2018)

Implementation of BIM in the organization

The hospital makes make use of BIM, for renovation and new building parts, as well as for maintenance, but the BIM process is still developing: the hospital feels that information is still often too fragmented, and communication is a critical aspect. . (Central information manager, personal communication, november 10, 2017) *(See quote 2.1.0, Well functioning communication)*

The hospital uses BIM in a cyclical way, and they also think about the process from initiative until delivery for operation and maintenance. A more detailed description can be found in appendix A.1.2.

BIM roles

The hospital also has an idea about the organization of BIM roles. BIM roles are e.g. BIM modelers, BIM coordinators and a BIM manager. According to the central information manager, the project manager should have a central role, and thus knowledge of BIM. (Central information manager, personal communication, November 10, 2017) For a more detailed description of the organization of BIM roles, see appendix A.1.3.

BIM vision

The hospital uses its own BIM protocol, with a BIM vision. De core points from the BIM vision are stated below. An elaboration of 2, 3 and 5 can be found in appendix A.1.4.

1. The building data should exist and be useable as long as the building exists.
2. Make use of open BIM, unless this is not possible (elaborating in appendix)
3. If open BIM is not possible, use of source data (elaborating in appendix)
4. In case of 2 and 3 are not possible because of required drawings or calculations, use of (2D) CAD
5. Working from course to fine with level of detail (elaboration in appendix)
6. An interim structural division of information and evaluation takes place (See figure 16 and table 5)
7. An open data structure is used

BIM phases and information level

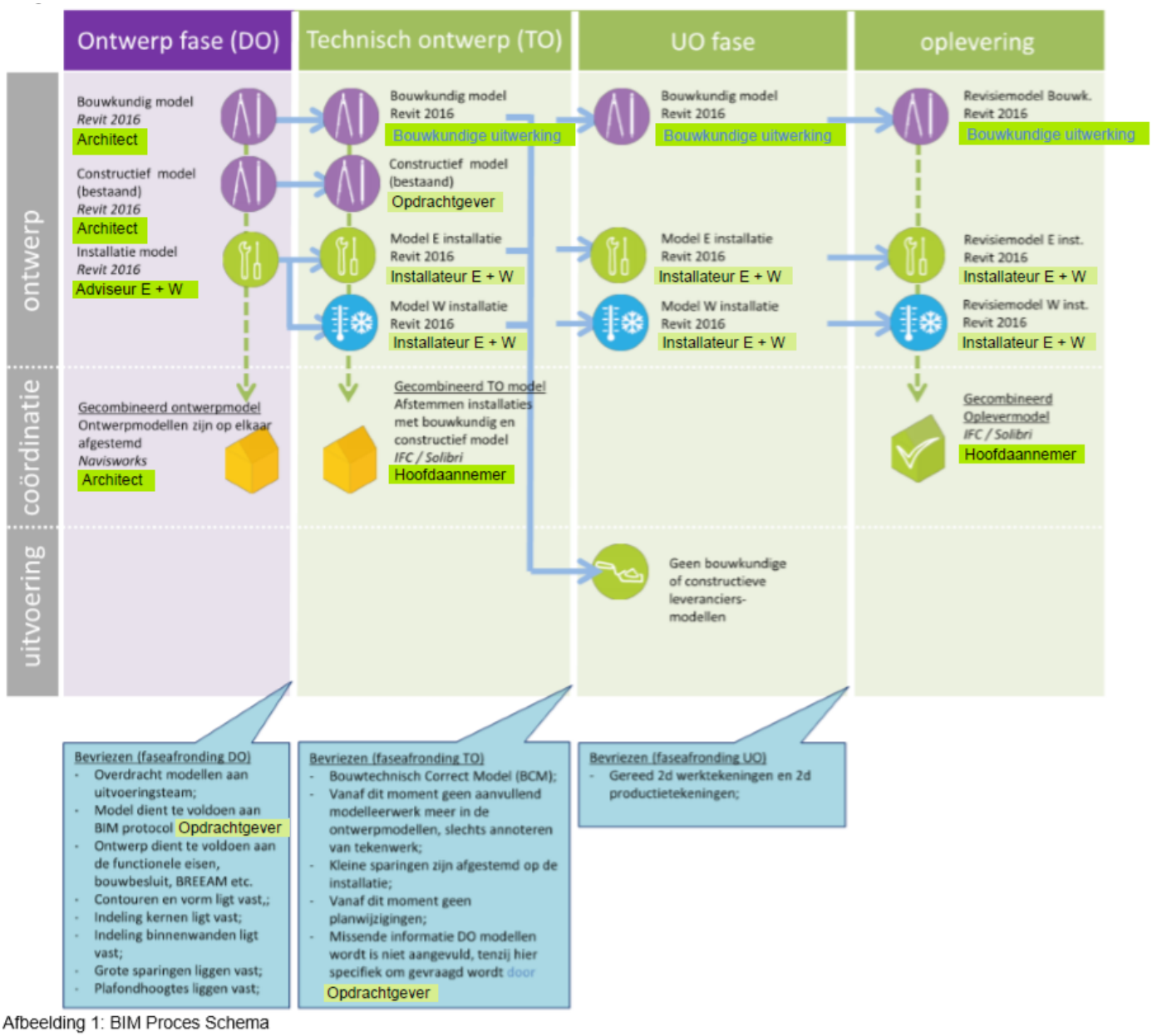
The information development is not always working out in practice, the way it is theoretically expected. Visualisational elaboration of the former can be found in appendix A.1.5.

The transfer from information to the operation & maintenance phase forms a challenge, because of a lack of availability and usability of information about buildings and installations. To cope with this, the following are required: an electronic building file (building information) and common data environment. New technologies can be

implemented, such as a 4D project calendar, sensor technology, and data analysis. It is essential that (project) management team members are willing to adopt the use of data generated decision making (Presentatie BIM project&beheer, 2017).

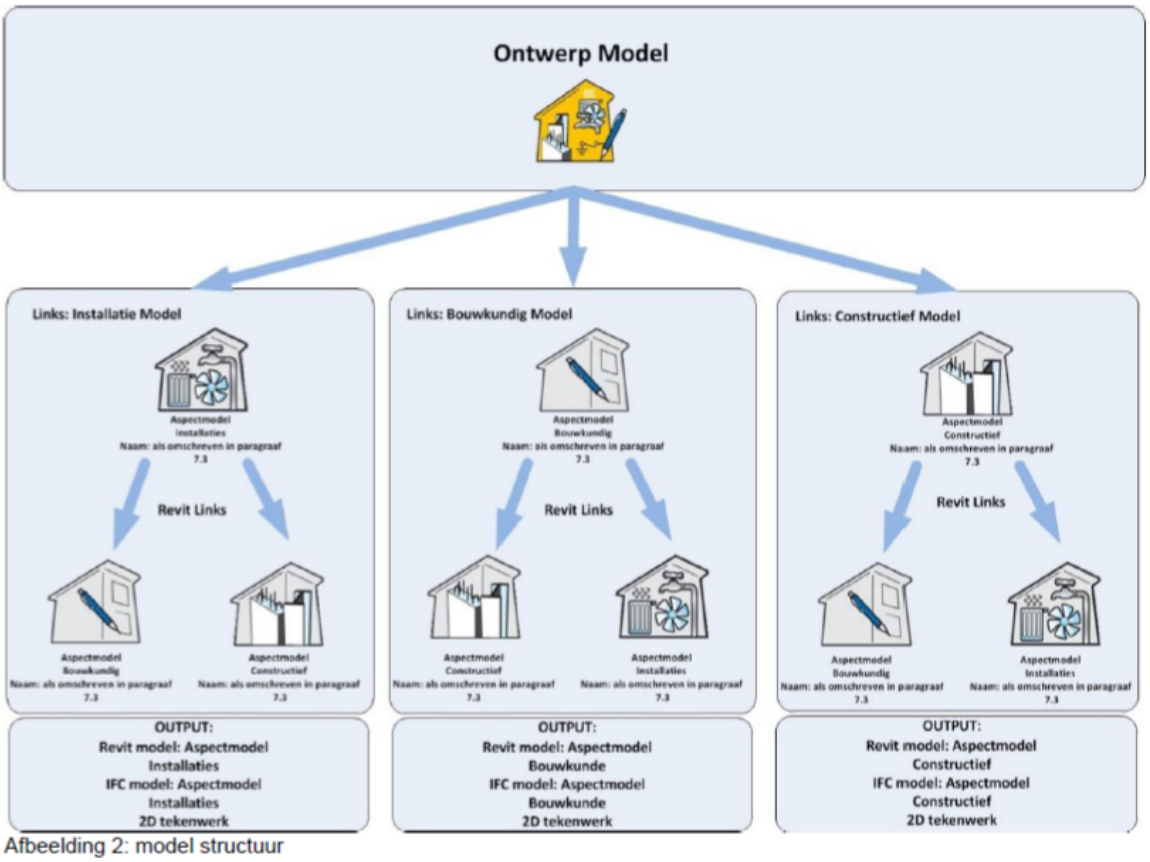
Use of BIM in the specific part of the project

The next figure 16 shows how the (BIM) process of the project is organized. Figure 17 shows the model structure of BIM in this project.



Afbeelding 1: BIM Proces Schema

Figure 16. Project partners and (BIM) process of the project. (BIM uitvoeringsplan, 2017, p 6&7)



Afbeelding 2: model structuur

Figure 17. (BIM uitvoeringsplan, 2017, p 10)

The model structure in the project was slightly different than given in the BIM execution plan:

We shared everything via Chapoo, a platform to put everything on, say. So the BIM models were exchanged, they were placed on Chapoo. Different models, not a combined model. So we have an installation model, and an architectural model.

"*Wij hebben alles via Chapoo uitgewisseld, dat is een platform waar we de boel op kunnen zetten, zeg maar. En zo werden ook de BIM modellen uitgewisseld. Die werden op Chapoo geplaatst. Verschillende modellen, geen gecombineerd model. Dus we hebben een installatiemodel, we hebben een bouwkundig model."*[1.1.3.] (Project manager, personal communication, April 10, 2018)

In the BIM protocol can be seen that the basic way of working with BIM is according to the Information Delivery Manual (Dutch: Informatieleveringspecificatie or ILS), a standard list of BIM related agreements. The ILS includes the following core points:

- Sharing information unambiguously
- Structuring information
- Securing (future) object information (BIM uitvoeringsplan, 2017, appendix A)

In appendix A.1.6. of this report, the Dutch version as in the BIM execution plan, and the English version of these manuals are included.

Communication with BIM

De communication with BIM is organized as follows:

3.6 BIM communicatie

3.6.1 BIM overleggen en overlegstructuur

Overleggen	Wijze van	Frequentie	Actie door
BIM Kick-off	bijeenkomen	eenmalig	Hoofdaannemer
Ontwerp overleg	bijeenkomen	2 wekelijks	Hoofdaannemer
Delen van modellen	Chapoo	2 wekelijks	mod.partijen
Clashcontrole	Solibri	2 wekelijks tijdens het ontwerpoverleg	Hoofdaannemer mod.partijen
Controle tussentijds 2D	PDF | DWG | DXF	in overleg	allen
Controle fase afronding	PDF | DXF | DWG | IFC en bronbestand	fase afronding	allen
Fase document	PDF | DXF | DWG | IFC en bronbestand	fase afronding	allen

Meetings	Way of/used program	Frequency	Action by
BIM Kick-off	Get together	One-off	Main contractor
Design consultation	Get together	Two weekly	Main contractor
Sharing models	Chapoo	Two weekly	Modelling parties
Clash control	Solibri	Two weekly during design meeting	Modelling parties
Interim 2D control	PDF | DWG | DXF	In consultation	All
Phase completion control	PDF | DXF | DWG| IFC and source file	Phase completion	All
Phase document	PDF | DXF | DWG | IFC and source file	Phase completion	All

Table 5, Communication considering BIM, between the different project partners. (Anonimized from BIM uitvoeringsplan, 2017, p 11)

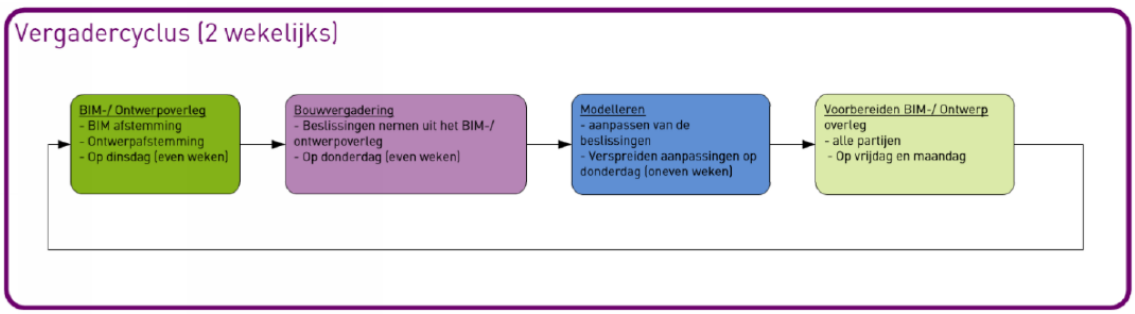


Figure 18. Meeting cycle. (BIM uitvoeringsplan, 2017, p 9)

Chapoo is used to share BIM information. Clashes will be reported in Solibri. For coding, the NL-SfB coding system is used. (BIM uitvoeringsplan, 2017, p 9&10).

Validation and verification (with BIM)

De models are being checked with Solibri model checker, a program in which the different models can be checked, and can be viewed by the project partners by means of the Solibri model viewer.

For every model, a entry quality check is done by the BIM coordinator or the the party who sends out the model, before the model is published. At the start, it is reviewed if the model meets the demanded BIM requirements. (BIM execution plan, 2017)

Figure 19 shows a possible model review.

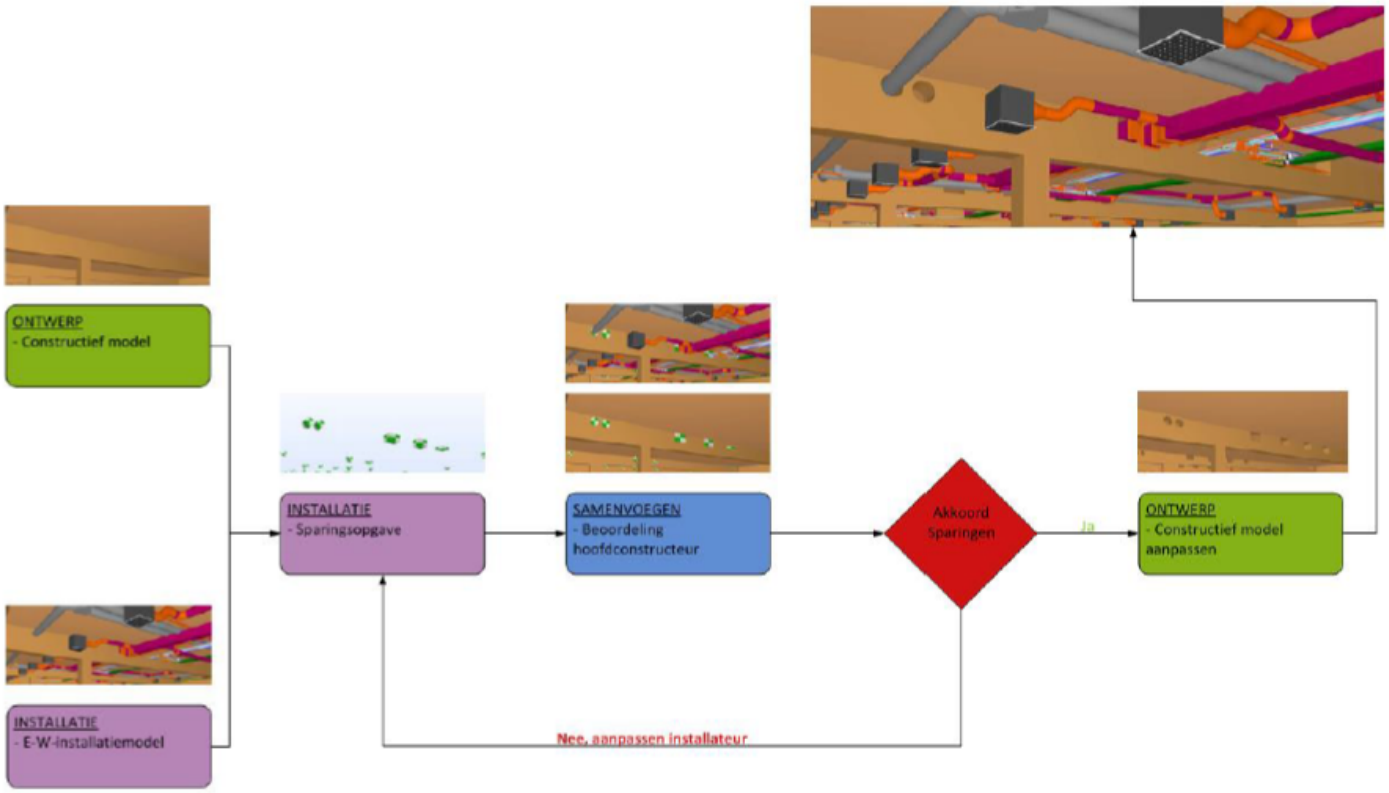


Figure 19. A possible model review. (BIM uitvoeringsplan, 2017, p 9)

Language and culture

All project partners are Dutch parties. However, parties can have different interests, which can cause friction:

"How is the relation towards BIM, look we as a client want to get a lot of benefits out of it (BIM), but you experience that the implementing parties are still a bit restrained, they do not want to put tóó much energy into it. They also experience time pressure, we will not finish in time, so it is always a bit difficult, you really experience that it is still a transitional phase."

"Hoe is de relatie tot BIM, kijk we, als opdrachtgever wil je er heel veel voordeel uit halen, je merkt dat bij de uitvoerende partijen er nog wel wat terughoudendheid is, die willen er niet té veel energie in steken. Want die ervaren dat ook, tijdsdruk, we krijgen het niet op tijd af, dus, het kost altijd een beetje moeite, je merkt echt nog dat het de overgangsfase is." (BIM manager, personal communication, April 10, 2018)

Case context: Foreign Hospital case

Contract form, project partners and their responsibilities

The Hospital, which is currently being designed, is a public procurement project of about 150.000 m2. (BIM execution plan, final version, 2016) The hospital is currently in the detailed design-preparation for tender phase. (Project architect, Foreign architects party 1, personal communication, April 19, 2018) The project partners participating in the project, and their responsibilities, are shown in table 6. The contractual relations can be found in Appendix A.2.1.

Company	Responsibility
Company A: Foreign party 1	▪ Architecture (design + closed structural work + fixed furniture)
Company B: Foreign party 2	▪ C&S stability ▪ BS MEP (electricity, medical gases, vertical circulation) ▪ BIM management (limited assignment)
Company C: Dutch subcontractor	▪ MEP (Mechanical + Plumbing) ▪ architecture – completion
Company D	▪ programming (functional + spatial)

Table 6. Project partners and responsibilities foreign hospital case. (Adjusted and anonimized from BIM execution plan Foreign hospital case, final version, 2016)

Project goals

The following table 7 shows the organizational goals in the project. A more detailed description of the goals is given in appendix A.2.2.

Priority (1-3 : 1 = high)	Objective	Potential BIM applications
1	Optimal coordination per design discipline	Design, Design review, 3D Coordination
1	Optimal coordination between design disciplines	Design, Design review, 3D Coordination
1	Optimally coordinated, correct and clear 2D/3D output	Design review, efficiency on-site
1	BOQ and 'Specifications' (tender file)	
2	Visualization (Internal only, not presentation)	Design review

Table 7. Organisational goals in the project. (BIM protocol Foreign hospital case, final version, 2016)

Use of BIM and BIM roles

Use of BIM: The use of BIM in the project is described in a BIM protocol and BIM execution plan. The BIM protocol shows how BIM is used in the project more generically, the BIM execution plan shows how BIM will be used in the project, more detailed and project specifically. BIM will be used in the project to work out the 2D design drawings in 3D in more detail. For collaboration, one specific platform, Buzzsaw, will be used, where all parties upload their models weekly. (Project director, personal communication, January 11, 2018)

The means of BIM in the project are shown in table 8, the exact BIM programs used are shown in table 9.

BIM Application	Description
Designs	A process in which 3D software is used to develop a Building Information Model based on program requirements, in this case Revit.
Design review	A process in which a 3D model is used to present the design to the client, users and other interested parties, and to gear it to the program and to evaluate it. Criteria such as lay-out, sight lines, lighting, safety, ergonomics, acoustics, textures and colours, etc. can be adjusted. Software: Navisworks, Revit, Design Review, DWF viewer... The program requirements will be managed through BriefBuilder.
3D coordination	A process in which Clash Detection software is used during the coordination process to locate building conflicts by comparing 3D models. The purpose of the Clash Detection is eliminating the most important system conflicts prior to the installation. Software: Navisworks, Revit.

The software that will be used in the BIM applications mentioned above, are worked out in detail in the 'BIM Execution Plan'.

Table 8. BIM applications. (BIM protocol Foreign hospital case, final version, 2016)

Means of use	Programs
Modelling software	o Revit Architecture 2016 o Revit Structure 2016 o Revit MEP 2016 o Revit 2016 o Revit LT 2016 (NOT recommended) o AutoCAD 2016 (if needed)
Software for 3D coordination	o Navisworks 2016 o Design Review 2013
Viewers	o Navisworks 2016 o Design Review 2013 o Buzzsaw

Table 9. BIM software used in the project. (Own table on basis of BIM protocol, 2016)

Later in the process, also Dalux is added as a program for 3D coordination, viewing and commenting. (BIM coordinator Architecture, Foreign case, personal communication, 2018) An overview of the BIM related project roles and responsibilities as stated in the BIM execution plan is shown in table 10. A full definition of the roles can be found in appendix A.2.3. The full responsibilities (*also connected to level of development*) can be found in appendix 2.2.4.

Function/Role	
General	***Foreign Company A - Engineering C&S***
BIM information Manager	BIM Coordinator STRU
Company A – BIM manager	BIM Modeller
Company B – Manager	***Foreign Company A – Engineering MEP***
Company C – BIM manager	BIM coordinator MEP
	BIM modeller
	Foreign Company B
	BIM Coordinator
	BIM Modeller
	BIM Modeller
	Dutch Company C - MEP
	BIM coordinator MEP
	BIM modeller MEP
	Dutch Company C - Completion
	BIM coordinator ARCH (completion)

Table 10. Project roles and responsibilities foreign hospital case. (Adjusted and anonymized from BIM execution plan, final version, 2016)

During the project, this structure was not used in every company, e.g. the Dutch subcontractor did not have a BIM manager, but only BIM coordinators for MEP and Completion. (BIM coordinator Arch, personal communication, April 30, 2018)

Model structure, using and naming models

The model structure of the project is as follows in figure 20:

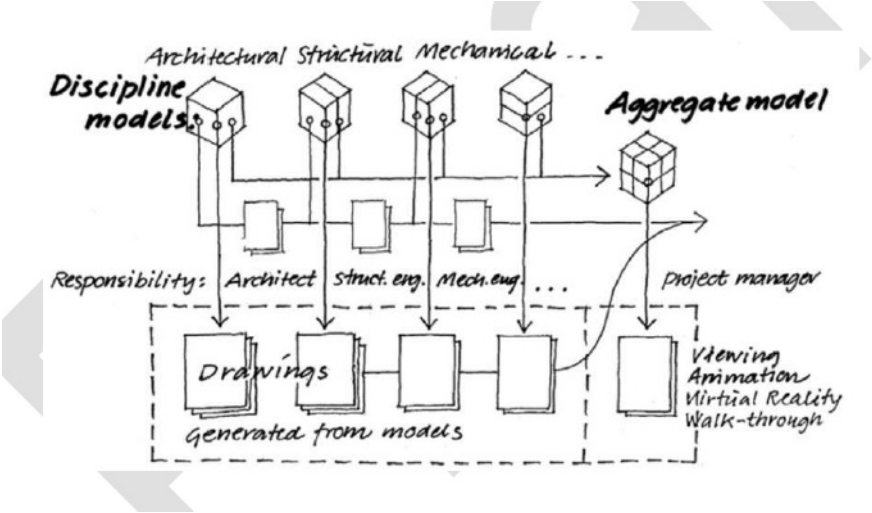


Figure 20. Model structure of the design parts by different disciplines in the project. (BIM protocol, 2016, p 10; BIM execution plan, 2016, p 33)

Due to the project size and its multidisciplinary character, not all information is stored in one model. Each party will construct one or more models, which will be linked together later to form a complete final model.
These partial ("aspect") models are kept as one ("bux") as long as possible. Divisions can be made in consultation with the BIM information manager. (BIM execution plan, 2016) A detailed description on how models are used and named can be found in appendix A.2.5.

Level of detail (LOD)

In the project, different levels of detail are used in the design. Level Of Design connects to the completeness of information of an element. Five levels of design are used in the project as shown in table 11. For detailed description of implemented LOD, see appendix A.2.6. For LOD responsibilities, see appendix A.2.4.

LOD	Description
LOD 100	**Mass study indicative** in terms of surface, height, volume, location and orientation and can be modelled in three dimensions or be represented by other data.
LOD 200	Elements are modelled as general systems or compositions with an **estimated** size, shape, location, quantity and orientation. Non-geometric information can also be added to modelled elements.
LOD 300	Elements are modelled as specific compositions and **accurate** in terms of size, shape, location, quantity and orientation. Non-geometric information can also be added to modelled elements.
LOD 400	Elements are modelled as specific compositions and **accurate** in terms of size, shape, location, quantity and orientation **with complete manufacturing and montage detailing information**. Non-geometric information can also be added to modelled elements.
LOD 500	Elements are modelled as actual constructed compositions **(as-built)** and accurate in terms of size, shape, location, quantity and orientation. Non-geometric information can also be added to modelled elements. This model is used in the maintenance phase of an object. Non-geometric information refers to; brand, type, colour, consumption, refresh cycle, etc. This model forms the basis for the "BIM maintenance".

Table 11. LOD in the project. (BIM execution plan, 2016, p 22)

Project partner	LOD to create
Company A: Foreign Architects party 1	300
Company B: Foreign Architects party 2	200
Company C: Dutch subcontractor	200

Table 12. LOD per party in the detailed design phase. (BIM execution plan, 2016)

Validation and verification

The review procedure in the project is as follows:

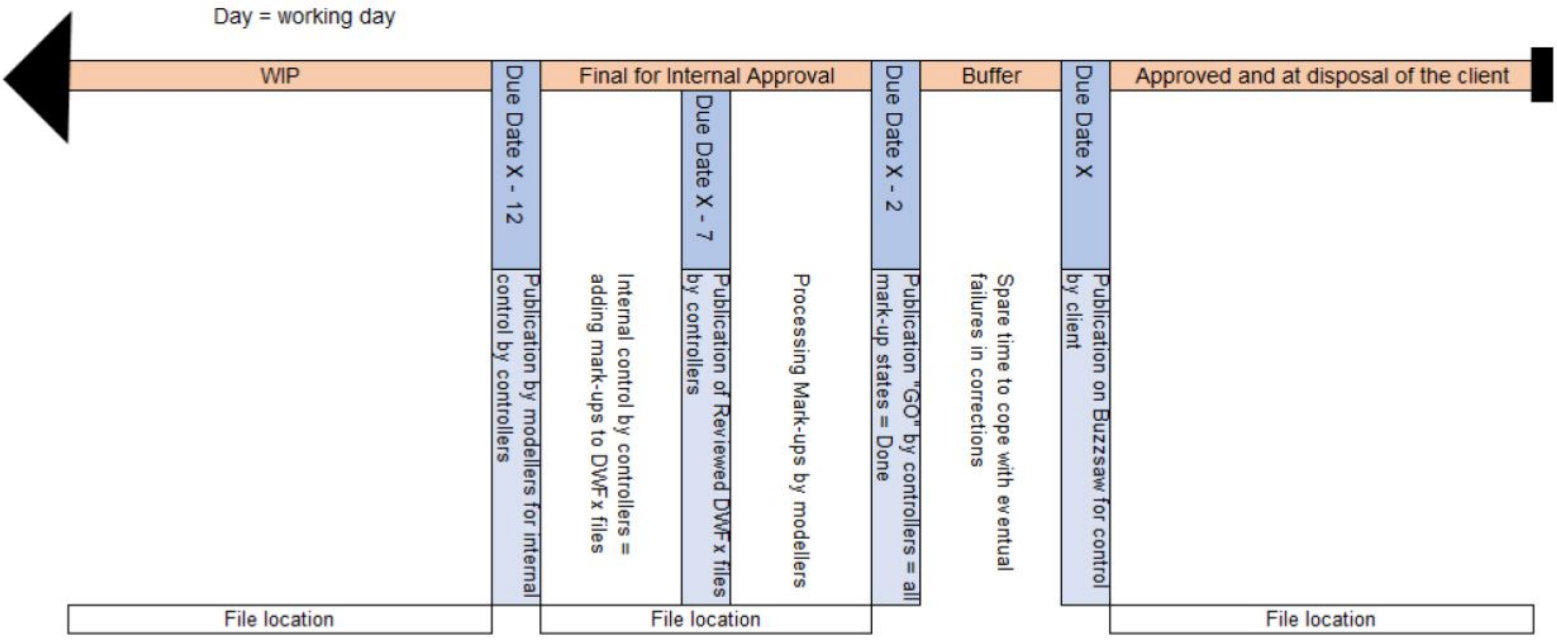


Figure 21. Review procedure in the project. (BIM execution plan, p 27)

The validation and verification of the design goes as follows:
"The designs (***sheets*** from Revit) are verified and provided with commentary on the DWFx in ***Design Review 2013***. A list with remarks will be kept on an Excel Sheet, accompanying the DWFx bundle." (BIM execution plan, 2016, p. xx)

The detailed procedure can be found in appendix A.2.7.

Language and culture

The involved actors speak different native languages. Although the "main project language" is set at English, sometimes actors speak with each-other in their own language. Some project actors speak all languages of the participating project actors. (Project director Dutch subcontractor, personal communication, January 11, 2018; Project manager Dutch subcontractor, personal communication, March 26, 2018)

Language with BIM

"The language used for modelling and naming files, families, styles etc. will be English.

The language for filling in the values of parameters, texts on sheets or in title blocks has to be [Foreign language], the language of the property developer.

All text appearing on the final output should be [Foreign language]!!" (BIM protocol, p 47)

Spoken language per project partner

Project partner	**Spoken language**
Foreign organization: Hospital	Foreign language, not all actors speak English
Foreign party 1	All three languages. (English, Dutch, Foreign)
Foreign party 2	Foreign language, some speak reasonable English, some not so well.
Dutch subcontractor	Dutch, English, one actor speaks the foreign language sufficiently.

Table 13. Spoken language per project partner. (Multiple interviews, observation).

Next to the language barrier, also cultural differences are an aspect (sometimes issue) in the project. There are e.g. different ways of looking at healthcare, hierarchy, and functionality of the project by the different parties from different countries. (Project manager Dutch subcontractor, personal communication, March 26, 2018)

4. Findings

In this section, the results of the different research questions are elaborated by the most speaking parts of quotes of the interviewees and atlas TI analyses. A table of all conclusions and quotes can be found in appendix C, the total atlas TI analysis in appendix D. The cases were analyzed on basis of the questions stated earlier, see methodological rationale – research questions.

Most mentioned codes in total	1. B1: Client/end users 2. B2: Project team 3. J3: Problem/possible improvement 4. K1: Manage/steer/coordinate 5. D1: Information/data structure 6. G1: Communication/information exchange 7. C5: BIM - what 8. J4: Transition/improvement 9. C8: BIM agreements/requirements 10. C6 : BIM - how	
Most mentioned codes per case	**Dutch case** 1. B1: Client/end users 2. B2: Project team 3. K1: Manage/steer/coordinate 4. J3: Problem/possible improvement 5. L: Role/profession 6. C8: BIM agreements/requirements 7. K2: Project/process/organization set-up 8. J2: Positive aspect/added value 9. G1: Communication/information exchange 10. J4: Transition/improvement	**Foreign case** Ten most mentioned: 1. B2: Project team 2. D1: Information/data structure 3. P2.1: Validation - what 4. J3: Problem/possible improvement 5. B1: Client/end users 6. P2.2: Validation - How 7. C5: BIM - what 8. G1: Communication/information exchange 9. C6: BIM - how 10. J4: Transition/improvement
Most mentioned codes for project team vs client	**Project team actors** 1. B2: Project team 2. B1: Client/end users 3. D1: Information/data structuring 4. P2.1: Validation&Verification - what 5. J3: Problem/possible improvement 6. C5: BIM - what 7. G1: Communication/information exchange 8. P2.2: Validation&Verification - how 9. K1: Manage/steer/coordinate 10. J2: Positive aspect/added value	**Client/end users** 1. B1: Client/end users 2. B2: Project team 3. K1: Manage/steer/coordinate 4. J3: Problem/possible improvement 5. K2: Project/process/organization structure 6. L: Role/profession 7. C8: BIM agreements/requirements 8. J4: Transition/improvement 9. C6: BIM - how 10. J2: Positive aspect/added value

Table 14. Most mentioned codes, by Atlas TI analysis. Underscored codes are different in the top 10. Elaboration in appendix D (D.4, D.6.1 and D.7.1).

From literature and from the interviews, different definitions of BIM as a communication tool can be seen: on one hand BIM as a 3D modelling programme, to design and to prevent or solve design errors (clashes), and on the other hand BIM as an information management

system, existing of one or more programs or tools to structure and manage information and communication.

Table 15 suggests that overall, BIM is mainly defined as a way to make agreements, as a 3D model and an information management model. In the Dutch case, BIM is stressed mostly as being a process tool. In the foreign case BIM is stressed mostly as being an information management system.

BIM definition	**BIM definition Dutch case**	**BIM definition foreign case**
Defining codes used in order	***Defining codes used in order***	***Defining codes used in order***
C8. BIM agreements C1. 3D model C2. Information management system/model C3. Process C4. Collaboration	C8: BIM agreements C3: Process tool C1: 3D model C2: Information management/ model	C8: BIM agreements C2: Information management system/model C1: 3D model C4: Collaboration tool C3: Process tool

Table 15. BIM definitions as coded in Atlas TI. Elaboration in appendix D (D.4 & D.6.1).

The various actors give different definitions to BIM:

"For me, BIM is just […] collaboration on basis of agreements made upfront, to which you have to comply so to speak, to deliver a project clash free." 0.2.1 (BIM coordinator Architecture, Dutch actor, Foreign case, 30-04-2018)

"if two or more programs are used, in which […] the sum of all programs used gives a coherent overall picture […] so, for me, Autocad and Word together are BIM, and Autocad, word and Excel, or whatever, are also BIM" 0.2.2.

"You could define BIM even as plain drawings. For me it is a building information model, […] 3D is a part of that, but not specifically that." 0.1.1 (Project manager Dutch case, personal communication, personal communication, April 10, 2018)

The change in roles as mentioned in literature is also experienced in practice:

"And often... how we see it now, is not to appoint a BIM coordinator or BIM director, but the project manager also becomes responsible for BIM. Of course one can be advised by BIM experts, but it is a part of the design meeting…" 0.1.3.

Also benefits of BIM as mentioned in literature such as cost savings and efficiency, are also seen as potential benefits in practice:

"And if you use BIM well, a lot of data comes up, which you can use to measure time, money, costs, insight and progress" 0.1.3. (Central Information Manager, Client, Dutch case, personal communication, November 10, 2017)

The former relates to the different ways that BIM can be used. As a starting point, different parties can have different motives for the use of BIM. For example, the reason why BIM was used was partly similar in both cases, considering the use of the BIM model for operation and maintenance for the client. Table 16 shows a comparison between the use of BIM in both cases.

Use of BIM in both cases

	Dutch case	**Foreign case**
BIM goals/motives – Why	For operation and maintenance for the client (1.1.1) Efficiency for the client in the engineering phase. (1.1.2.) Clash detection between designing parties. (1.1.5) Calculation and planning. (1.1.6)	For operation and maintenance for the client (1.1.2) Clash detection between designing parties (1.2.2.) Quantity take off for cost calculation. (1.2.3)
Use of BIM – What/ How	A 3D model for maintenance. It was intended to use 3D throughout the process, but the client stepped back to using 2D. (1.1.4) 3D models were exchanged between the designing parties, the hospital was not involved in this. (1.1.5) The client reviews the model with the design team and end users in 2D. The main contractor looks in the model for bottlenecks. However, 2D plain drawings are also used.	BIM was implemented in the detailed design phase. A 3D model was made in Revit from 2D drawings.(1.2.4) For the installations part, a combination of excel, dynamo and Revit is used." (1.2.5) For the architecture part, they work with Revit, Navisworks and Autocad. They work together in a shared Revit server model.1.2.6 Dalux is later implemented to validate and verify the design.(1.2.7, 3.2.5)

Table 16. Use of BIM in both cases

*"One of the most important reasons for the client to choose for BIM, was the use of the information in a later phase for maintenance and facility management"*1.2.1 (BIM manager Foreign hospital case, Foreign party 1, Foreign case, personal communication, May 8, 2018)

"It is mainly, how it was used here, we mainly used the building model, so 3D drawings, and the information component is mainly: what should I carry out? Now, we are mainly looking at if we can connect the information component for delivery towards maintenance. Now I think it is separate, so not connected." 1.1.1. (Project manager, Client, Dutch case, personal communication, April 10, 2018)

In the Dutch case, BIM was also used for calculation and planning.

We further use BIM models to calculate and plan. 1.1.6 (BIM director, main contractor, Dutch case, personal communication, June 1, 2018)

Other reasons for the use of BIM in the Foreign case are clash detection and to calculate cost ("bill of quantities"):

"That will be a sort of kick-off meeting, in which also agreements will be made on how we work with clash detection." 1.2.2. (Project director, Dutch actor, Foreign case, personal communication, January 11, 2018)

"Here in [hospital location] they mainly want a BIM model to calculate the bill of quantities." 1.2.3. (Project director, Dutch actor, Foreign case, personal communication, January 11, 2018)

"The basic setup for the model is quantity take off. From [country] they assigned codes, so everything that is in the model, should have the right coding. […] So the conclusion of BIM is, that finally, cost management can determine from the model what prices and elements are in it." That requires a certain specificness… And one has to model conform that, one can take into account clash detection, when something goes through the concrete, one has a certain margin, then it is, they have to adjust it. One has to model precise. Finally the 'sheets' are extracted from it, but that is a bit of a side issue, mostly, calculation of the quantities is important. 1.2.3 (BIM modeler, personal communication, May 16, 2018)

A motive for the use of BIM in the Dutch case was efficiency in the engineering phase (detailed design phase):

"it really is about communication I think, and that stays fragmented, separated, instead of one central model, in which you look together at the same thing… I feel like communication takes much more time by working with different systems, they and we. And I think, […] when you look together at a BIM model, and work together in that way, you may be more efficient. I do not know if that counts for the design phase […] but it does for engineering. So when they really start designing, I see possibilities." 1.1.2 (Central Information Manager, Client, Dutch case, November 10, 2017)

These reasons and motives for the use of BIM are connected to the way how BIM is used in the project. In the Dutch case, high BIM ambitions were set at the start of the project about working together in 3D, however, due to the process, BIM was used to a lesser extent later in the project. Although the designing parties used 3D models for clash detection, the client checked the design by means of 2D drawings generated from 3D models, instead of the 3D models themselves. .

"At the start, we transferred the BIM protocol to the contractors. And certainly in the start we tried to hold on to it. Although, quite soon that did turn out not to be workable. Then […] we released the BIM process, or actually 3D drawing, and started managing the process on basis of 2D drawings. […] In fact we expected progress, […] we were discussing more what should we do, what should we not do, and the quality of the delivered DO (final design) model was not enough to continue. […] So [hospital] was not organized to check 3D models. They wanted to see plain drawings. And also for

construction they wanted plain drawings, at some point I thought, I am pushing and pulling to get it in BIM, but it is not carried by the whole team […] Then I said, we release it, although I still want you (the executing parties) to deliver drawings from the 3D model, so at the end I have a 3D model, agreed in the BIM protocol." 1.1.4. (Project manager, Client, Dutch case, personal communication, April 10, 2018)

"I know that [Main contractor] and [Advisor Electrical&Mechanical] have exchanged models multiple times, in those control rounds, clash control rounds, I, or [hospital] actually, was not involved anymore, because, not that interesting anymore." 1.1.5. Project manager, Client, Dutch case, personal communication, April 10, 2018)

"I occasionally look into a model to examine certain bottlenecks. One notices that subcontractors still work with (plain) drawings. The carpenters outside as well, by the way. That is why I am also preparing 2D drawing work." […] "The model is located at us [main contractor]. We are the BIM Coordinator during the work. The work has now been completed and we have added a revision model to the revision pieces and this is again managed by [hospital]." 1.1.7 (Work planner, main contractor, Dutch case, personal communication, June 11, 2018)

In the Foreign case, BIM was implemented in the detailed design phase. The different programs that were used where amongst others Revit, Autocad, and Navisworks. Although 3D collaboration was intended, often 2D communication was still used:

"For this project, BIM was implemented in the 'detailed design' phase. The conceptual design was drawn in 2D in Autocad and sketchup. The preliminary design was made as a model in Revit, although a BIM process was only started from the 'detailed design' phase. Information was still often exchanged in 2D/dwg, because not all parties are convinced of the BIM principle." 1.2.4 (BIM manager, Foreign party 1, Foreign case, personal communication, May 8, 2018)

The Dutch subcontractor makes use of different BIM models, for installations and for architecture:

"For the installations part […] at this time, the designers fill in something in Excel, and we import that into the model, with a number of programs. We do not really use a data base yet […] mostly we work with a combination of Excel, Dynamo and Revit." 1.2.5 (BIM coordinator MEP, Dutch actor, Foreign case, personal communication, May 7, 2018)

"We work out the architectural model. Linked to that we have the constructive model, and the casco model, the façade. We use Revit to work out everything for the quantities, and from which we also generate the drawings. Further, Autocad is used to get the furniture in order. […] And for clashing the models, we use Navisworks. […] We work together with a revit server, […] that is just a central location for the model, though which you can work together on a model with multiple people, also from different locations." 1.2.6 (BIM coordinator Architecture, Dutch actor, Foreign case, personal communication, May 8, 2018)

Now the setup is that we have two models, one architectural model that contains all the information, and a separate model, solely to show the 2D information. Often when the models are going to be very heavy, then it could be that we separate the models further, but it is useful to have as much information as possible in one model, because when things change, then you have to change all the

models, and load the families again. 1.2.7 (BIM modeler architecture, Dutch actor, Foreign case, personal communication, may 16, 2018)

Later in the process of the Foreign case, another program, Dalux, was added, in which the different project partners could communicate, and also the client could place remarks on the design:

Until this week the design was always validated in a traditional way, on basis of 2D drawings, although in combination with the model to have more insight. Starting this week, the Dalux platform became active (Dalux field), and the final design is validated via Dalux tasks and issues. 1.2.8 (BIM manager, Foreign party 1, Foreign, case, personal communication, may 8, 2018) - *See also quote 3.2.5 (Validation&Verification)*

RQ2 – well functioning communication and BIM model

When looking at BIM as a communication tool(RQ2), as seen in literature, different hard (technical) aspects of the BIM programs, as well as soft aspects such as communicative skills and other skills are of influence.

In order to establish a well-functioning process while using BIM, many actors state that good communication is key, both with and without use of BIM. In the Dutch it is often mentioned, as well as (to a slightly lesser extent) in the Foreign case, that communication is a critical aspect, which can influence outcome of the project. (See table D.6.10 & D.6.11). The project manager of the Dutch subcontractor of the Foreign case elaborates on the importance of good communication and collaboration for the project outcome:

"We all worked together in a model independently. Every Friday we uploaded everything, and then, regardless of how big the clashes were, everything was put in one model. Then on Tuesday, we had a clash detection meeting. And in the BIM execution plan was stated what we considered a clash. Then we sat around the table, and those parties looked, then there was a clash detection chairman, who said, I see this clash, we have to do something with it. And then an action was created, because someone had to make space, or a pipe had to be relocated, redesigned, […] well that way of communication has to happen. Because otherwise everyone really do their best […] it is in fact working together in a chain, that has to lead to one end product. If it is not going well in the chain, the end product will not be good as well." 2.2.1 (Project manager, Dutch actor, Foreign case, personal communication, May 8, 2018)

BIM can influence the communication and coordination in the project positively or negatively:

"If you mean the use of BIM and Revit, than I would say it is no different than ten years ago. Communication is all-defining. […] I even think it is more complicated nowadays, because this is not yet common practice." 2.2.2 (Project manager, Dutch actor, Foreign case, personal communication, May 8, 2018)

"clients expect 2D drawings mostly. Or they find it easier. But we make a model anyways, because you can use it for much more, such as calculating lengths of pipes and cables. And to coordinate problems. Yes, I worked a lot with 2D in the past. And it is so much easier to solve problems in a 3D model." 2.2.3 (BIM coordinator MEP, Dutch actor, Foreign case, personal communication, May 7, 2018)

In the Dutch case, BIM is used to collaborate and communicate:

The BIM implementation plan of [main contractor] is linked to the request (BIM protocol) of the [hospital]. Next, it is up to [main contractor] to ensure that the suppliers keep sight of the BIM implementation plan of the realization phase that falls within the scope. As soon as there is a gap in the BIM protocol information, it is impossible for a supplier to fill in properly." […] "All models should be made in IFC, in accordance with the BIM Protocol of [hospital]. The communication is based in BCF / BIM Collab. In addition, it is a process in which there are also sessions where people come together to coordinate / clash. Furthermore, the usual ways of communicating are also considered with BIM. The "C" from BCF is collaborate = collaboration, that is what makes the work a success in the end." 2.1.1 (BIM director, main contractor, Dutch case, personal communication, June 6, 2018)

The central information manager sees benefits and potential from using 3D to involve end-users by showing them the design:

"Yes, certainly. I think more people understand an image where a space is drawn with data, or at least a 3D, with: here is the window and there is the door and that is so and so, than that they can read from (plain) drawings. And technicians will be able to do so because they are trained to read (plain) drawings, but users rather see a combination. […] In the hospital there are people that are never involved in construction." 2.1.2. (Central information manager, Client, Dutch case, personal communication, November 10, 2017)

The hospital makes use of virtual reality to include staff in the project, although it is merely used to give them insight, and not used to let them make design decisions:

"Virtual reality, yes, that you really walk through a model, or can connect images from the model to a place where you stand in reality, […] but it is not a standard part of the design process. […] to show users […] how we cope with this, yes that helps, absolutely. […] it is used to give them some insight, but not to let them make decisions. […] And that is what you actually want, that they can make a choice about where a door or room is located, to calculate walking distances […] but we are not there yet. […] I think that there is a need for that. You can cope with more complex starting points because it becomes visual. And if you use BIM for all of that, it will become measurable as well." 2.1.3. (Central information manager, Client, Dutch case, personal communication, November 10, 2017)

Although communication is seen as a critical aspect, it is often stated by the interviewees that communication and the way information is structured can still be improved. (Appendix D, table D.4.5) Amongst others, the communication in the Foreign project is not really happening directly between the Dutch subcontractor and the client, but going via foreign party 1. (*See Figure 23 and also quote 3.2.2. and 3.2.3., Validation and verification)*

According to the BIM manager of the Dutch case, BIM does not really have a central role in the project as a communication tool yet:

"As a client, you want to get a lot of benefits out of it (BIM), but you experience that the implementing parties are still a bit restrained, they do not want to put tóó much energy into it. They also experience time pressure, we will not finish in time, so it is always a bit difficult, you really experience that it is still a transitional phase. […] You would rather see that spaces get defined by dimensions. At that point you say: what are the requirements, do not start with a 3D model, but mostly which information should be added to a space. For example, how many electrical outlets does the end user want. Then it contains a certain knowledge structure, and that is wat you see preferably. But at this time there is still much room for improvement." 2.1.4 (BIM manager, Client, Dutch case, personal communication, April 10, 2018)

As stated in literature, in the establishment of a well-functioning communication and collaboration with BIM, actors' skills and competences can play a role. Also in practice, the importance of competences was stressed. (appendix D.4.8, table D.6.18 & D.6.19) In the Foreign case, not everyone knew the program Dalux yet, among which the BIM coordinator for the Architecture part. A workshop day, and test pilot, were organized:

"Dalux is... No, I did not (see Dalux) yet, [BIM coordinator MEP] has seen it sometime. I saw the workshop last week, and it is no higher mathematics. It is just a matter of adding the right parameters to what you want to upload to Dalux, and from there you can view and review the model, and place remarks. Then you can also reply on the remarks you receive, or which you have to resolve in the model." 2.2.4. (BIM coordinator Architecture, Dutch actor, Foreign case, personal communication, April 30, 2018)

Later, the BIM coordinator MEP was interviewed, after the Dalux test was done, which was experienced positively, in terms of usability of the program:

"We already did a test (with Dalux), that went well. But I am curious what the client thinks of it, as when they are able to work with it well, we have to create less 2D drawings, which helps us, as we only have to make sure the model is accurate. […] Yes, it looks good, it works really fast, compared to Revit or such, this is much easier. What is also possible, is to import 2D drawings, […] so you can view 2D drawings, and also really see how it works in 3D. It is very intuitive, and you have much more information. […] It works very well […] to manage and to see what is finished and what is not. […] The idea is that that first [foreign party 1] places a remark, and then the client. And then we make sure it will be processed well and replied on." 2.2.5. (BIM coordinator MEP, Dutch actor, Foreign case, personal communication, May 8, 2018)

According to the BIM coordinator Architecture of the Foreign case, For a well-functioning information exchange, it is also important to get to know each other and meet with each other face to face:

"Internally, MEP and architecture are still a bit two loose parts. And the communication with [foreign party 1] is also a bit stiff, which has to do with the way of building in [foreign country], and then you have a [foreign] client, so that communication makes it difficult, English is still sometimes that we talk through each other. I have to say that, now we have been at location twice, that has its benefits. Also now, in the email communication, it is not that distant anymore. Internally, for the Architecture part, the communication is just fine. I mean, we are all accessible, we can view with each other, we do not have to be at location. We can look via skype, call, discuss. But it is still nice to be here (at location) one or two days a." 2.2.6. (BIM coordinator Architecture, Dutch actor, Foreign case, personal communication, April 30, 2018)

RQ3 – validation and verification

Looking at the validation and verification of the design and BIM model (*RQ2*), different ways of validating and verifying are found in the case studies. Validation connects to the set requirements in the projects. Verification connects to reviewing the BIM model and design between the different stakeholders. Figure 22 shows the validation in the Dutch case.

According to a project director of the Foreign case, validation and verification of hospitals design is often done by means of user consultations:

"With hospitals […] because that is an enormous culture of user consultations and so on, actually the requirements take place on the way, even more." 3.2.1 (Project director, Dutch actor, Foreign case, personal communication, January 11, 2018)

In the Dutch case, as mentioned before, the design is verified between the designing parties and the client by means of 2D drawings. The 2D drawings are generated from the 3D model. Internally, the hospital validates also in 2D. The designing parties conduct clash detection in 3D.

The work planner of the main contractor states the following about validation and verification:

"There is always just one party that can validate, and that is the end user. The only thing that I can think of right now is to validate a design by means of VR (virtual reality), but how representative is that compared to reality... We are not involved with validation in practice. Verification is part of our daily activities. For this, a separate tool is not used." 3.1.1. (BIM director, main contractor, Dutch case, personal communication, June 6, 2018)

The internal requirements of the hospital for validation of the design specified by the Central Information Manager:

"Yes, partly from legislation. Partly also from policy from [hospital], either for use, so cleaning, what are the requirements, cleanliness requirements, such specifications, unit infection prevention and safety […] the other is existing installations, so that we tell people from property management that something has to connect to the existing infrastructure. And the other is, […] collecting the information, furnish parts, that can differ. So that are the requirements that you always include in the tender, so someone knows what to make, and to which context. 3.1.2. (Central information manager, Client, Dutch case, personal communication, April 10, 2018)

Considering verification, the project manager checks if the quality of the BIM (3D) model is fit for operation and maintenance:

"I am now checking the models that you saw, from what there is now, what is the quality, and can we use the quality well in our maintenance and management." 3.1.3. (Project manager, Client, Dutch case, personal communication, April 10, 2018)

Further, the BIM manager checks the quality of the BIM model during the process:

"Then something has to be thought about the quality, to make sure the models that come from the advisors towards the implementing parties are good enough to work out further, so that means that from both sides people are pushing and pulling, because on the one hand we ask a certain quality of the implementing parties, but that means that the models from the advisors have to be good enough, without that we have to add a certain translation or extension, in the sense of details or such, so in fact that means having a good conversation with both parties. […] and then it is also my task to comment on that, is it correct, is it really correct, is the critic justly, can one also expect that certain information is present in the model or not, and in which phase. 3.1.4. (BIM manager, Client, Dutch case, personal communication, April 10, 2018)

The project manager manages the internal verification (2) of the design in the Dutch case.

"plain drawings, provided via Chapoo. […] [Hospital] is not yet ready for a 3D test. We want to do it but it is not yet that way. […] When you get skillful in that together […] I think it is useful, because then you have just one medium, that is just, when it is a translation of drawings again, this just comes all from one thing, so it cannot go wrong. So that is certainly better. Now, in this project, plain drawings are generated from the 3D model, and those are checked and validated by the involved parties. We just have verification matrices for that, in which everyone can place comments, and I manage those verification matrices, I have to make sure all comments that are made, are or being said to not be implemented, or are processed in the next process." 3.1.5 (Project manager, Client, Dutch case, personal communication, April 10, 2018)

According to the Central Information Manager, the hospital uses the following process to include the opinion of end-users to verify the design:

"Well, we have a quite tight process for that. First we ask if there is a need within the organization for a sort of building or space. […] then we work that out further with a design team, and at a certain moment they (the end users) get an 'agreement drawing' as we call that, which shows the exact agreements of what they get, that much space, […], with that amount of windows and doors, that many electrical outlets. They sign that, and then it is designed .. and then they get feedback when we deviate. […] Then they approve again, […] until it is finished. And then are not informed for a while, because then it is really being built. […] And at the end of the process we deliver again to them: look, this was the agreement drawing, this is wat you got, so this works in that way. And sometimes we need them halfway during the process, to elaborate on a device that they bought and which can influence the design. Well, they come with it themselves as well, as in: well, I bought something new, can that be included?" 3.1.6. (Central information manager, Client, Dutch case, Personal communication, November 10, 2017)

The project manager gives an explanation about the verification matrix (Dutch: "toetsingsmatrix") they use, and elaborates on the internal verification of the design by around 20 end-users from different parties:

"(The verification matrix) is just an excel model, a plain comments matrix, in which everyone can comment on categories, everyone has his own role, and validation is pre-defined. We work following Prince-2, a project management system, […] we pre-define the stakeholders: who has to check what, is responsible for which part. Everyone looks with a limited scope. That makes a hospital so complex, and that is why communication is so important[…] We have a radiation protection unit, that are two people. We have BHV, 1, we have access control, 2, we have routing and logistics, 1, we have two people from the facility service. We have an installation inspector, we have a structural inspector, that makes 12 already. Then we have 3 of the department itself, so the department of users, so the working user, nuclear medicine [department], which is represented by 1 person, but they have tested with 3 of them. So these are the actual users, that is a user representative, a department manager and user.. eh process manager or something. And then we have also testers at the building office. […] Well, that is, the architect, the constructor, the installation consultant, […] they (the internal reviewers in total) are 20 people at least. […] Validation and verification is, for me just internally." 3.1.7. (Project manager, Client, Dutch case, Personal communication, November 10, 2017)

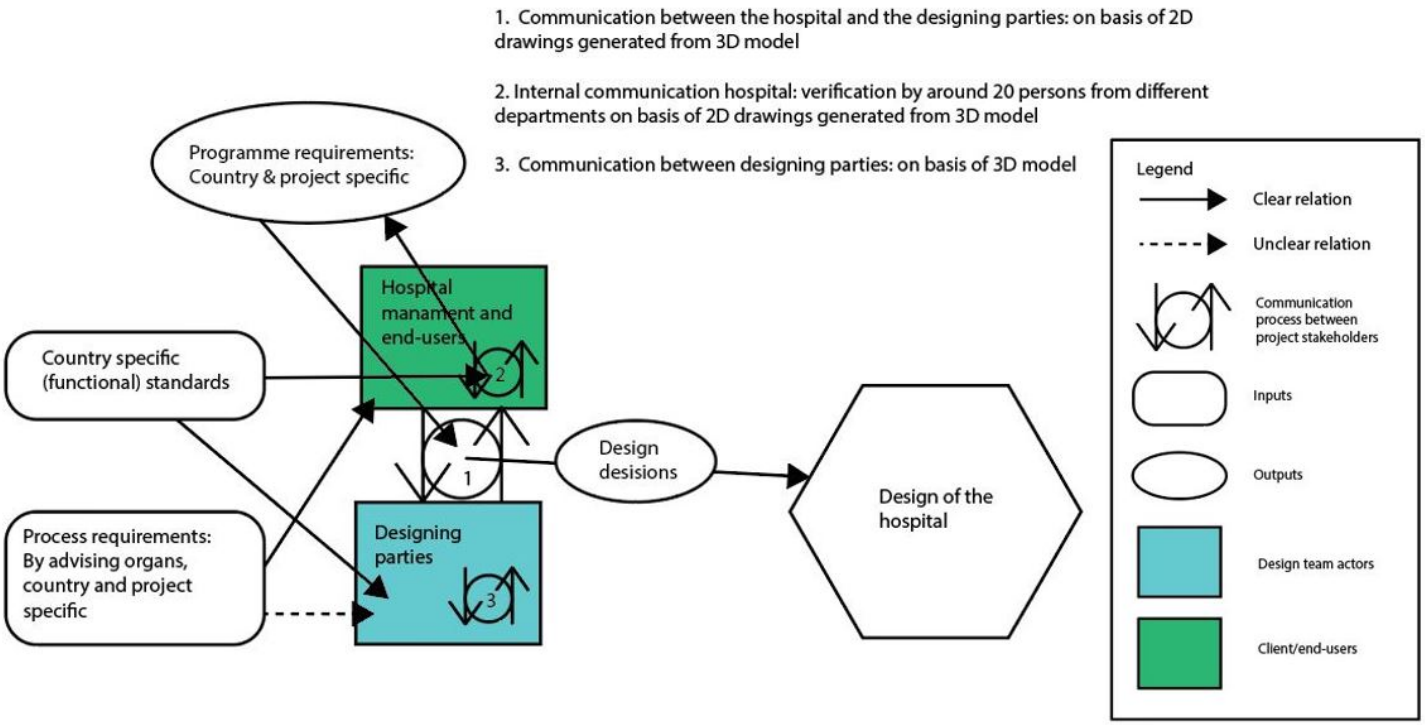


Figure 22. Representation of communication, validation & verification in the Dutch case. (BIM manager, personal communication, April 10, 2018; Project manager, personal communication, April 10, 2018)

Validation and verification in the foreign hospital case

Validation and verification in the project happens internally (within the different companies), and between the different parties of the design team, as well as between the designing parties and the client (hospital). Figure 23 shows a representation of the communication, validation and verification of the Foreign hospital case.

As was stated before, the communication is mostly between the foreign architects and the hospital(1), and between the Dutch subcontractor and the foreign architects(2). The communication between the Dutch subcontractor and the hospital is only happening sporadically (3).

"Actually, we do not know that end user that well. […] we work as a subcontractor for [foreign architects party 1]. And they conduct the user consultations, and the conversations with the end client so to speak. We are never a part of that, we have some reports but they are all in [foreign language] so we read those difficult or bad, or not. So we really work on the input that we get from [foreign architects party 1]."[3.2.2]. (Project director, Dutch actor, Foreign case, personal communication, January 11, 2018)

According to a project manager of the foreign hospital case, the communication via the foreign architects is sometimes a challenge. It would be easier to verify design decisions by discussing things with the hospital staff directly. However, the language barrier to a

lesser extent, and the stronger hierarchy in the foreign case (compared to the Netherlands) to a greater extent influence this way of communicating:

Sometimes we would really want to ask something directly to them (the client). If you ask a doctor, for example why it should be 23 degrees all the time, then it is much better to discuss this directly than that it goes via via. […] So I think due to the (non)fluency of speaking [language], and certainly also due to the hierarchy, and the relations that count there, that it was said some time, it has always to go via us (Foreign architects party 1). Well, that is sometimes a pity. I never experienced it that way in the Netherlands."[3.2.3] (Project manager, Dutch actor, Foreign case, personal communication, March 26, 2018)

The design is validated and verified according to functional criteria, which differ per country, and to the program requirements (Dutch: Programma van Eisen). The country specific criteria are leading.

"The actual validation and verification, compared to a program of requirements, and consequently the design that you make, is not as relevant as in the situation that you as a designer get a program of requirements, and get started. The verification and validation thus is following more following the requirements, the standardized regulations, that apply in [country], then to a program of requirements. A recent example, well a recent change, is that, we have our hematology department, and well, for such a department requirements apply in the Netherlands, so you have to refresh the air in a room that often, temperature X, humidity Y."[3.2.4.] (Project manager, Dutch actor, Foreign case, personal communication, March 26, 2018)

Earlier in the process, the design was verified between the design team and the client, by means of plain drawings (as stated before) and also by mock up rooms. A project architect of the foreign architects party 1 stated the following about the involvement of end-users in the verification:

"many, a minimum of four per department, of which one or two are deputed to verify. For example, the technical department. […] The mock up rooms were tested by around 150 people." "Not every end user can read a plan, or knows what to do with it […] then we explain more during the meetings" […] " it depends per user what they can read per scale […] sometimes they think the rooms are too small" […] "end users are nurses or doctors." […] "we do not work out everything in 3D, because it takes too much time and energy to put everything in 3D. During the programming phase we often had to work out different variants" […] "The mock up room was actually built, windows and walls were placed" [3.2.5] (Project Architect, foreign party 1, personal communication, April 19, 2018)

Later in the process, the design is verified between the design team and client(2) by means of comments in Dalux:

"We are going to communicate, say, by uploading the models in another viewer, say, Dalux viewer, [...] soon I am going to actually upload the model, then we are going to test it, that is actually the pilot. And then it will be applied so that the client can take a look at drawings, and in the model. [...]

we actually give orders to check the model, so they can submit comments, and we will have to process them."[3.2.6.] (BIM coordinator Architecture, Dutch actor, Foreign hospital case, April 30, 2018)

When sharing information between the design team and the client, it is important to know which information the design team needs, and what the client needs:

""A client also gets a lot more (information), of which in many cases he does not know what to do with it. Or he has not yet developed a process for himself, to use it. So, one has to explain a lot more, and one has to think much better upfront about: what does my client really need?"[3.2.7.] (Project manager, Dutch actor, Foreign case, personal communication, May 8, 2018)

The external verification between the Dutch subcontractors and foreign party 1 goes as follows and can also be seen in figure 23:

"So what we do is, we first check internally, then we send something (to foreign party 1), then we check it [at foreign location], an appointment is planned for that, and the comments that come up there, are implemented back here in the Netherlands."[3.2.8.] (Project manager, Dutch actor, Foreign case, personal communication, March 26, 2018)

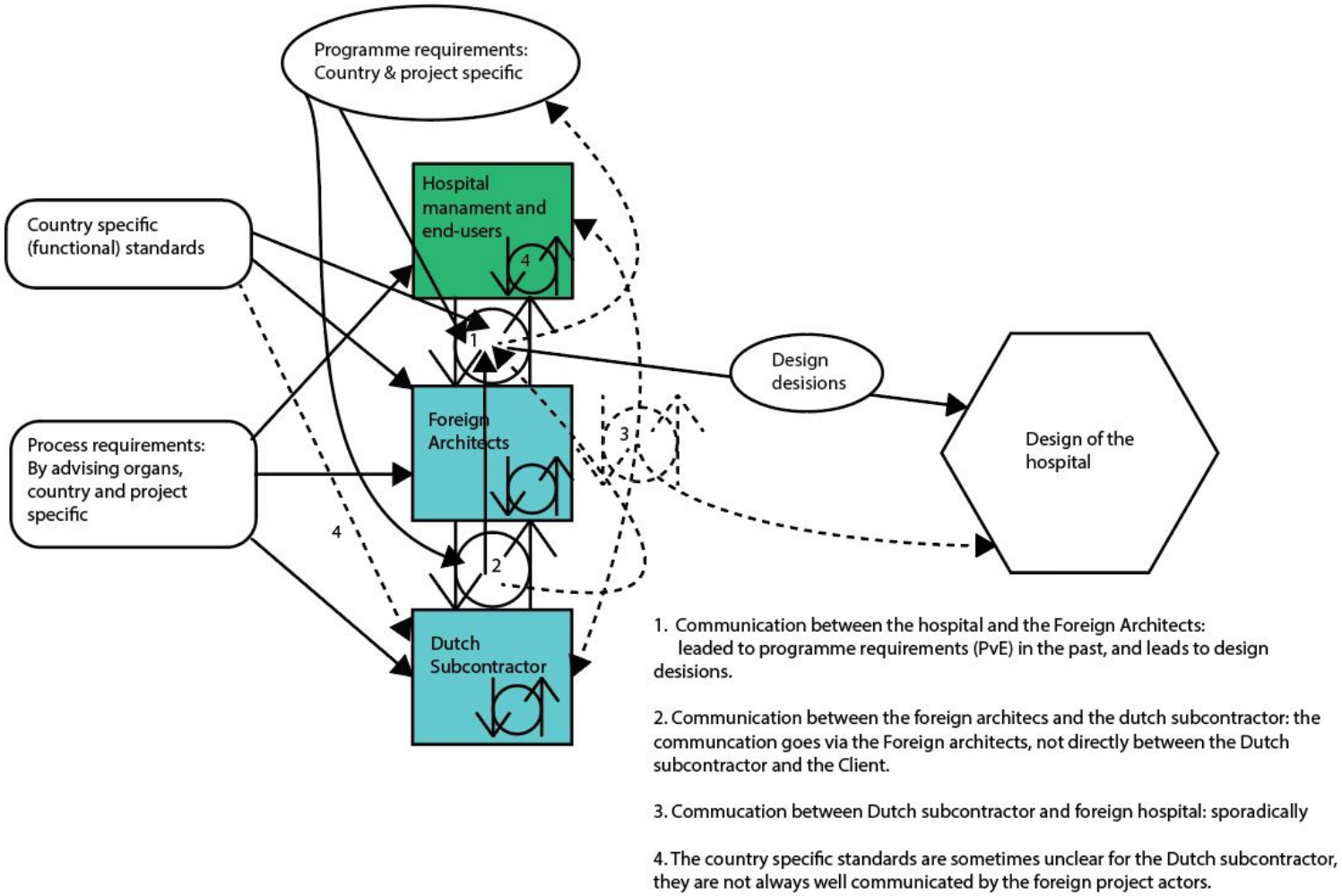


Figure 23. Schematic view of the process of communication, validation and verification of the design. (Several interviews, quotes in text below)

The internal verification between the parties of the Dutch subcontractor is as follows (see also figure 24, part 1 and 4): clash detection is conducted to solve design errors, for MEP, for Architecture and for the MEP and architecture part together, also "scrum" sessions are held to discuss progress. After the internal validation, the design is checked between the different parties again

"We try not to cause clashes at first, that is the best. It takes less time to do it right at once, than to solve everything. So we are often together to plan work amongst the disciplines. And we have a project meeting once a week, where things like that are discussed. And then we only conduct a clash detection at the end of the piece of work, to check how that goes." 3.2.9. (BIM coordinator MEP, Dutch actor, Foreign case, personal communication, May 07, 2018)

"we cannot clash with construction, […] say that there is a beam, and the wall clashes with it, it crosses it, then one can cut a piece out of it, but one can also say: it crosses it, and it is a clash we accept, but that should be settled well beforehand." 3.2.10. (BIM coordinator Architecture, Dutch actor, Foreign case, Personal communication, April 30, 2018)

"So that is internally, actually […] we are also going to clash with MEP and the interior model, before we export it to [foreign party 1], and then there will be a clash control by the client. And the client of our client also looks through the model. They will probably look in another way, so to speak, at the usability, if things should be done differently, and Dalux is used for that. The clashing will be done with Navisworks, so for the internal clash, say, we use Revit, clash detection. So we have... clash controls like MEP, architectural, interior, which we do with Navisworks. So we have to deliver that also. And consequently [foreign party 1] is going to clash with Navisworks as well. And all the models will be on Dalux later, and that will be for the client of [fp1], our client. They can give comments, […] No, the comments go to [fp1], and [fp1] forwards them, so we do not have direct contact with the Hospital." 3.2.11. (BIM coordinator Architecture, Dutch actor, Foreign case, Personal communication, April 30, 2018)

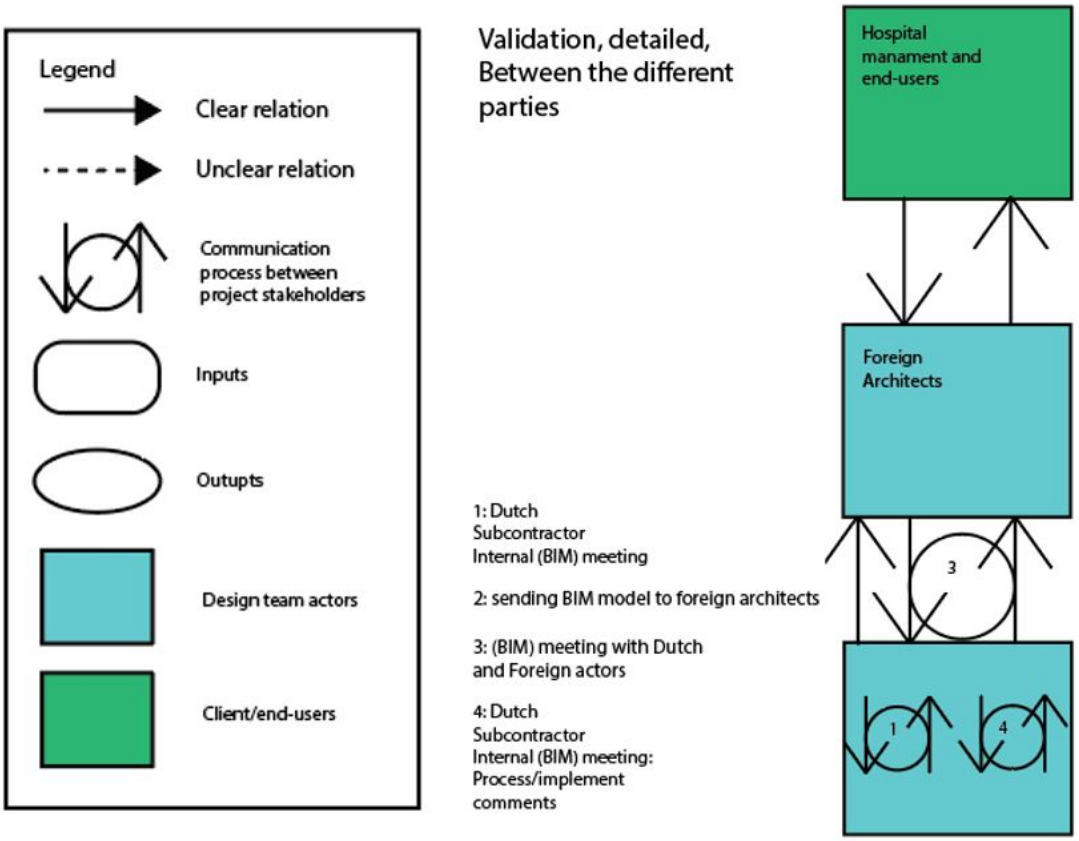


Figure 24. Detailed validation and verification of the design between the Dutch subcontractor and foreign architects. (Interview project manager, Dutch actor, quote 3.2.10)

RQ4 – collaboration and work process

It was often stressed by the interviewees that making good agreements up front about the way of working with BIM is critical for outcome (see appendix D, tables D.4.4., D.4.8, D.6.2 – D.6.5 and D.6.8). Also, in the Dutch case, making good (BIM) agreements are often mentioned as critical for a well-functioning team process. (See table D.6.16) Also in the foreign case, the former is stressed:

"In another project for example the agreements were not made well, and then to get the right quantities from the model is really, […] intensive work. […] Sometimes I miss that modelers work in a standardized way [..] Too often, thing do not meet the requirements, to extract it (the quantities) decently. At [Dutch subcontractor], they are creating a central library now, including all standards, now everyone works a bit for themselves. And those are things, which can, and should be much better." 4.2.1. (BIM coordinator Architecture, Dutch actor, Foreign hospital case, Personal communication, April 30, 2018)

The BIM modeler of the Foreign case stated the importance of working conform the same protocol and coding, being precise, and streamline and document things well:

Yes, I have to say that in this project, it goes quite well, then I talk about the modelers, [name] and I are a bit more experienced modelers, but there are also some less experienced modelers, but in fact, we all think conform the same protocol, and everyone does their best to, stick to the coding and fill in in everything if you make a wall, and, that is of course also very important with BIM, It is not just quickly placing a wall, you really have to check everything, height, which parameters are filled in, if the departments are correct. But I think, in this project, it goes quite well" […]

"In the end, it is very important to state in the protocol to which requirements you have to comply. But also, now we set up a bit how we are going to model something physically, how we draw the wall, do you do that only on basis of levels, or also in space usage? Of course one can model in many ways, taking into account naming, or some… on the floorplan you see this is green [shows a floorplan in the model], that is because it is for example a MEP element. Light gray is then loose furniture, and black is fixed furniture, that. That set-up we created and we had contact about it with [foreign party 1]. But well, I documented that somewhere, as much as possible. Yes, it is of course important, when you work in a big team, to streamline all of that as much as possible. But I have to say that, when you are a bit settled in the project, it goes automatically. […] and one can always, in case of doubt, ask questions and communicate, that stays of course super important in such a project, otherwise one can easily import the information at cross purposes. That would be a pity." 4.2.2.

(BIM modeler architecture, Dutch actor, Foreign case, personal communication, may 16, 2018)

It was stated multiple times by actors from both cases, that the collaboration and work process with BIM can as well be affected by the (BIM) skill level of the people who participate in the project. (see appendix D, tables D.4.9, D.6.18 & D.6.19)

The following was stated by the BIM manager of the Foreign case:

"In this case the process was influenced negatively by BIM, by the lack of knowledge of BIM and 3D modelling in Revit by some parties. From experience in many other projects (hospitals and other) I can say that the knowledge of BIM and 3D modelling is very determinative for the success of a BIM project. The lack of knowledge and will to use BIM are often funest for a BIM process and too often cause a negative experience. However, when all parties have extensive knowledge and will, working with BIM is positive for all parties! 4.2.3. (BIM manager, Foreign party 1, Foreign case, Personal communication, May 8, 2018)

The BIM manager of the Dutch case also mentions the influence of BIM related skills in connection to the work process:

"On the one hand you say, what is experience with BIM? For some people it is knowing how to 'operate the buttons', opening a 3D model and extracting something from that, and to add something to it. On the other hand, it is also about a new way of working. Not everyone has experience with a BIM process. That is why you see that in a number of areas, and in a large amount of projects, next to the project manager, who does not have that much experience, or next to a design manager, in an implementing party, there should always be people, that you can ask questions, regarding BIM."

"On the other hand, the way of working, if you see BIM as a sort of flow chart, […] it is not per se different than what you do normally, the certain way of working so to speak. You only use other tools, and yes, the result in the sense of a model as a communication tool is different than what you are used to. […] But the problem is a bit, you still often see that people go back to familiar ways of working, so the traditional way of working. And that is because, when a planning is not achieved, there is additional work […] then people go back to the old way of working." 4.1.1. (BIM manager, Client, Dutch case, Personal communication, April 10, 2018)

The project manager of the Dutch case sees benefits potential of the BIM work process, but some steps have yet to be taken:

"In the past you had to check drawings and the work planner or the people that were involved, had to translate the drawings as in: does it work in 3D, in reality. That is now automated, and that has added value. I think the failure costs, for a contractor, or every one of us, will decline eventually, I believe so. But we have to take a few steps yet." 4.1.2. (Project manager, Client, Dutch case, Personal communication, April 10, 2018)

In hindsight, the process was more traditional than was intended at first:

"It has become a nice to have instead of an agreement, because, mainly in construction, […] to work traditionally." […] And for this project, that was the most important to work with. So we do modelling, and are simplifying our project protocol, while we hear experiences back… if you do not use BIM in the project, then you do not need all kinds of steering data, so you do not have to deliver those." 4.1.3. (Central information manager, Client, Dutch case, April 10, 2018)

The former was emphasized by two actors of the main contractor:

In case of [part of the hospital] there is only one supplier that uses BIM. That is the installer that falls under the control of [hospital]. Regarding the construction works, it are parts of which no supplier models are required. The design model for the UO (execution design) has been taken over by [main contractor] and is converted in accordance with the parameter list of [hospital]." 4.1.4. (BIM director, main contractor, Dutch case, personal communication, June 6, 2018)

In this project I did not experience a lot of that (added value of BIM for the work process) myself. We have mainly used 2D drawings. Although I do think that [kropman] has had benefit from it. The BIM

model was a contract in the agreement that we concluded with the [hospital] for the renovation. Because of this, sometimes we have been able to look into the model, which we had to do in case of doubt about the elaboration of details. (Work planner, main contractor, Dutch case, personal communication, June 11, 2018)
The work planner did experience the collaboration well however: *"Good, but I realize that it is extremely important to make clear agreements up front about the responsibilities of each party."* 4.1.5. (Work planner, main contractor, Dutch case, personal communication, June 11, 2018)

The central information manager mentions the importance of the way the hospital was involved and steered the process, as well as the fact that all parties should have the ambition to work with BIM:

"Yes, more involvement from our side, to organize the BIM process and show more benefits of BIM, but if the rest does not use it, then there is no benefit. You need to want it all together. […] But we cannot really steer, because then our own organization should be fully conscious, and behave in a 'BIM way', and also it should be agreed on in the contract, so there are quite some things that are connected to that. […] BIM is a means, and not a goal. And if this means did not work now, we have to see why it did not work. And in theory, it all works perfectly, but then everyone needs to really want it (work with BIM), and then we, as a client, have to steer the process in another way. So, more people at the table at the time, more expensive hours, but with that also being able to switch faster, dare to switch and decide, and be able to decide. We have to redesign our own organization." 4.1.6. (Central information manager, Client, Dutch case, Personal communication, April 10, 2018)

By mentioning the effect of BIM on the work process, the BIM manager of the Dutch case mentions other circumstances which affect the collaboration and work process. The collaboration and work process are influenced by e.g. time pressure:

"Once it was decided to work with Briefbuilder […] That is actually a database program, in which […] one can define per space what the design starting points are, so […] room temperature, or amount of electrical outlets, the amount of light, and that will be imported into the model as data. The idea is that you link that with the data in your model, to be able to validate it. But that process is released at a certain moment in this project, because the workflow was not there, so to speak. So there is a certain time pressure, or it has to come from the client like [hospital], because the designing parties do have not really developed that way of working yet. But preferably you would like the data which is linked to the model, to have a certain life cycle. You start quite course, and the amount of data should increase, and preferably, without doing things twice, should be reused in the project. But that does not work perfectly." 4.1.7. (BIM manager, Client, Dutch case, Personal communication, April 10, 2018)

RQ5 – readiness for use

Considering readiness for use of the BIM model in both cases, this is not yet perfectly ready. It is stated multiple times by the interviewees of both cases that the connection between design and use is still in transition (see appendix D, tables D.4.9, D.6.20 and D.6.21).

First, it is important to know which information is needed for maintenance. The required information in the Dutch case is the following:

"You also see that in management. We do not manage what kind of wallpaper is on the wall, as well as what kind of cylinder, what kind of locks, although one could say those could be added. So it is mainly installation components. Where are the fire dampers, and the valves, things like that." 5.1.1. (Project manager, Client, Dutch case, Personal communication, April 10, 2018)

The information should be well structured…

"If you think about documents, a clear folder structure, what is located where, and how everything is connected, what is the status of the document, and if you talk about data, it should all be structured and filled in the right way. We have around 40 components that we want to know, so you have to think about: is it an object in the model, or an object on a drawing that has to be maintained, what is the maintenance interval, is the warranty still valid, what kind of data is generated by that. That kind of data, those question we ask repeatedly. […] categories, and how you can retrieve it. If all pumps in the building are named pump in the same way, we can retrieve them, we set requirements for that. And requirements for location, that we always know where something is located, in which room, building, floor and space. That triad always needs to be followed, because then we can from our side select everything in a building, or in a floor or space, or combinations of that" (Central information manager, Client, Dutch case, personal communication, November 10, 2017) 5.1.2.

…to be used easily for operation and maintenance.

"Then you know much better where something is located for maintenance and management. Because one should be able to report malfunctions, when you need something on that floor, or in that space the door does not work, which door is it then… […] And then there comes a moment in the process when one really purchased the doors, then we know, and then it has to be implemented. […] And we say how it should be done. First we had difficulty with indicating ourselves how to do that. The last half year we invested time in that, and in indicating a list of things that had to be done, divided per discipline, so those forty things also are divided in four/five disciplines, so with your own discipline you have to do maybe twenty things. And we are doing that now, also an example Revit model where we imported it in well, so one has an example about how to do it." 5.1.3. (Central information manager, Client, Dutch case, personal communication, November 10, 2017)

In the Dutch case, the central information manager expects the model to be interesting for operation and maintenance:

"The end product will be interesting for maintenance. Then when the transfer to management goes a bit easier than in other projects, then we did well. And that is what we now steer on, but we only get the chance for that in the last phase, because apparently traditionally, everyone is used to solve that well in the last phase. I think it is possible to organize it well from the start, but well, we did not get steering on that. But for now it is fine, just bring it on. […] But I have all hope that we can get the data better and more structured, than in the past with paper folders, PDF's or USB sticks, unorganized. 5.1.4. (Central information manager, Client, Dutch case, personal communication, November 10, 2017)

The work planner sees the connection between design and use, but it is still in transition.

"Yes, certainly, the only difficulty is that [hospital] does not yet know how exactly, and that they are still sorting it out. They are quite far with it however, but there are still always some unclear areas which have to be considered." 5.1.5. (Work planner, main contractor, Dutch case, personal communication, June 11, 2018)

The BIM director of the main contractor states that using the model for maintenance and management is not yet common practice:

"Considering the works that [main contractor] does, it (this project) is a common process. The only difference is that [hospital] has the request to do maintenance by means of the model in the future." 5.1.6. (BIM director, main contractor, Dutch case, personal communication, June 6, 2018)

The BIM manager of the stated that the current model is not yet ready at this point in time:

Not yet, because, we are still in a phase, from the advisor to the [hospital], it (the BIM model) still has to go to execution, but it is also our role to make sure that the model is filled during execution to go to maintenance without too much effort. […] So that all kind of data is generated, to give an example: when the execution phase has started, when a detailed design has been made of the installation model, because that is the one we have in front of us. If I click a grid, than I should be able to see in which room it is located, how much air is going through it, and when it was last maintained. That is certain data, that I want to have. One could use that. So we still have to make a transition, from generic information to "as built" information, which we want for maintenance. But I see it happening. Now, the requirements for the models are pretty much in order. So that means it just has to be checked well, that it really happens. 5.1.7. (BIM manager, Client, Dutch case, personal communication, April 10, 2018) '

In the Foreign hospital case, the BIM manager stated the following about the readiness for operation & maintenance:

"One of the most important reasons for the client to use BIM, is use in a later phase for maintenance and facility management. In [country] we do not have a lot of experience with it, but it gets more and more attention. Also, FM tools are not yet aligned for working with 3D models... But big projects take many years, so a client with vision chooses for BIM already, because in a few years, the FM world will certainly be ready enough to work with the information" 5.2.1 (BIM manager, Foreign party 1, Foreign hospital case, personal communication, May 8, 2018)

The project architect of the Foreign architects' party stated the following about the use of the BIM model for operation and maintenance:

"Yes, but then we are not involved anymore." […] "One of their (the client's) questions was: to include a marker to each object, when a light is not working anymore, they have to replace it" 5.2.2. (Project architect, Foreign party 1, Foreign hospital case, personal communication, April 19, 2018)

A difficulty with the connection between design and use can be found in the difference between the information needs of the parties in the different phases:

"What is going very bad, and then it goes - that is the easiest - from the design industry to the construction industry to the use&maintenance industry. There is very little friction, because the management world has actually little or no demands for the data they want from the construction world. […] And you see that the management industry, I think that is very important, is actually not represented in that discussion, not clear enough. They do not claim their place sufficiently. This has also to do with the fact that they are stuck to maintenance budget which are always being cut off. […] But what also happens is that from the traditional world, where drawings in Autocad are made, everything is stripped towards the management world completely. Because it actually involves spatial management and static planning, as in why do I have to paint and how much surface is that? […] So in that translation a lot of data is lost, traditionally already. And no one has a good answer yet for the data that was generated in the design phase, in which even more data is added from the construction industry, because then specific data for the construction period is also popped up and added. The contractor then throws a lot of information away. You see that also, and then he adds his own design information. And then that is thrown away as well because the management industry wants something else." [5.2.3.] (Project director, Dutch actor, Foreign case, personal communication, January 11, 2018)

5. Discussion

In literature, different BIM definitions are given, from a 3D model to design and show the design, and to detect clashes, to an information model to manage, communicate and share building information between different stakeholders of the whole project lifecycle. In the *empirical research*, BIM was defined by participating actors merely as a way to make agreements, in the Dutch case as a process tool and in the Foreign case as a way to share and manage information.

It is stated in literature that BIM can be used very well in complex project such as hospitals: BIM can for example be used to include end users during the process. The benefits of BIM, as stated in literature, can be amongst others a better integrated communication and collaboration, efficiency and cost savings, and a higher design quality. The potential of BIM was also stated by *interviewees from both cases*, amongst others easier visualizations, problem solving and cost calculation.

In literature different ways of setting up BIM processes: communicating BIM specifications can be done amongst others via BIM standards, protocols, and execution plans. Communication and collaboration within BIM can be done via various programs, such as collaboration for Revit and BIM360. These programs can be used for example within IFC, a free open environment. *In Both cases*, a BIM protocol and execution plan were used. Reasons to use BIM were in both cases to use the model for operation and maintenance by the client, as well as to detect clashes between the design team members. In the Foreign case, BIM was also used to calculate costs of parts of the design.

<u>The use of BIM in both cases differs a bit(RQ1):</u> In the Dutch case, high 3D ambitions were set up front, however, the client stepped back to checking 2D drawings, generated from the 3D model. In the foreign case, 2D and 3D were used, between the design team as well as for checks by the client.

It was also found in literature that communication and information sharing can still be a critical aspect in the BIM process. Different actors from the design team and client, as well as from the different building phases have different information needs. Further, competences of involved actors can play a role in an (un)successful BIM process. Actors need technical BIM related as well as communicative skills. Also, the perception of roles and expertises of actors who work within BIM can differ between the own expectations and expectations of others.

<u>Considering communication and information exchange(RQ2)</u>, many interviewed actors stated good communication is key, whether using BIM or no BIM. However, a perfect communication was not fully reached in the Foreign case: the communication went merely via one of the foreign parties, instead of directly between the client and the Dutch subcontractor. For a wellfunctioning communication, it was stressed that a positive

influence could be achieved by meeting face to face and to getting to know each other. Further, interviewees stated that actors' competences can influence the communication. In the Dutch case, this was handled by means of a Dalux workshop, which was given by the BIM manager.

Considering the usability of the programs, in the Dutch case, working fully within 3D BIM did not turn out to be possible, partly due to the fact that the hospital organization was not ready to work within BIM. In the Foreign case, a pilot with Dalux was experienced positively.

Literature showed that the connection of data and the communication between different stakeholder that work in the design and use phase is important as during the design phase the functionality for the use phase is defined, and the use phase is the longest phase of the building life cycle, and thus it is important that this functionality is well designed. To define the functionality of the design and BIM model, these will have to be validated and verified.

The validation and verification (RQ3) of the design differed in the two observed cases. Some similarities could be seen, e.g. regarding the legislation that was used as a basis for the programme requirements. Also in both cases, clash detection was used amongst the designing parties to resolve design errors. However, there were differences between the two cases, considering the verification of the design, between the client and the designing parties. In the Dutch case, the verification was done on basis of 2D drawings, generated from a 3D BIM model. In the Foreign case, the client is able to review the design by placing remarks on 2D and 3D views.

Further, in the Foreign case, there was more distance between the client and the Dutch subcontractor, so the verification took place mainly between the Dutch subcontractor and foreign party one, and between the client and foreign party one, instead of directly between the client and the Dutch subcontractor, which was seen as an irregular and sometimes inconvenient way of working. In the Dutch case, internal verification was done by around 20 persons from different departments.

According to literature, next to communication, also collaboration and work process are affected by skills and competences of actors, as well as by the way of communicating specifications between each other.

Actors of both cases mentioned the skill level of participating actors as critical for a successful collaboration and work process (RQ4). Also, sometimes the expected skill level of participating actors, was different than the skill level as experienced in the project. In the Dutch case, the work process with BIM is seen as having potential, but some steps have yet to be taken. For instance, the process turned out more traditional than intended. Reasons for this were the BIM skill level of participating actors, but also the way the hospital steered the process, and the fact that all participating actors should have the same ambition about working with BIM.

Further, making good agreements was stated as critical by multiple interviewees, although this does not always guarantee success, due to other circumstances in the process, such as time pressure and changing ways of working which people have to get used to.

Regardless of BIM, language and culture can have their impact on project processes, e.g. by means of communication difficulties due to language barriers and hierarchy, as well as different ideas about functionality. Although, within the same language and culture, also conflicting interests of different parties can play a role.

As discussed before, *literature* showed the importance of a good connection between the project phases, especially the design and use phase, due to the fact that in the design phase the functionality for the use phase is designed, and the use phase is the longest phase of the project lifecycle.

Considering readiness for use(RQ5), from both of the two observed cases, the BIM models are not yet ready for operation and maintenance in the use phase, due to the fact that these are still being developed. An important consideration in this topic, is the difference in needs for information between designing and operating parties, and the way this information is communicated amongst the different actors. The needs for operation are mainly installation components, in terms of maintenance intervals, warranty details, and where these components are located. In order to use the model for operation and maintenance, the information should be well structured, by categories, names, and location in terms of building, floor and space.

6. Conclusion, recommendations and further research

The main research question was:

In what way are the **functionality of the design of hospital buildings, and the suitability of the corresponding BIM model** for the **use (phase), validated and verified** between the **various stakeholders,** while they (may or may not) use **BIM**, and what are the **critical points** for a **successful process**?

The way that these aspects are validated and verified, depend on the project and the different actors: validation often comes from country specific requirements (laws), and also partly from requirements set by the hospital. Considering verification, designing parties use 3D programs for clash detection and in the Foreign case also for cost calculation. The client has a more reviewing role: in the Dutch case they switched from 3D to 2D, and in the Foreign case they just started to include the client in the process with 3D. To conclude: the way the design and BIM model are validated and verified, and to which extent BIM is used in this process, are influenced by actors profession, knowledge and skills, roles and interests, as well as cultural aspects such as language and hierarchy.

The critical points for a successful process are the following:

1) BIM is often still seen as a goal, instead of a means. It is important to know upfront what the reasons and goals are to use BIM, and how BIM can be used to achieve these goals. Also, good agreements should be made upfront about this.
2) BIM is not a way to just resolve design errors, but also a way to involve all different stakeholders, amongst which the client. It should be defined upfront what the interests and skill levels of the different actors are.
3) It is not always so that the client (in this case: hospital and end users) has extensive knowledge of BIM, and consequently knows why and how to use BIM. In that case, it should also be the responsibility of the project team, that often has more knowledge of BIM, to help the client with this.
4) BIM and 3D and digital communication should not be things that replace real life communication. It is important to come together regularly during the project and keep communicating face to face.

In the managerial implications at the end, recommendations are given on how to implement the former critical point before, during and after the project.

In literature, different ways of using BIM were found: e.g. 3D models, a tool for solving design errors, and as a means to make agreements, communicate and share information. The different interviewees had different definitions of BIM. Considering the way BIM was used (RQ1), in the Dutch case, first high ambitions were set, for working with BIM in 3D, but due to problems in the process – e.g. different interests of stakeholders, time pressure, structure of the organization – the client went back to checking 2D drawings from the

designing parties. In the Foreign case, BIM was used to a large extent: not only for coordination, cost calculation and 3D clash detection between designing parties, but also for the client to give comments on 2D and 3D images of the building in Dalux. Because not everyone was familiar with this programme, a workshop was given to explain the way of working with it.

Communication is stated in literature as often still a critical aspect in building projects. This importance was also seen in practice: many interviewed actors stated the importance of good communication(RQ2), although this did not always work out in practice as was expected and wanted by different actors. In the Foreign case, the communication within the project was not always clear. The subcontractor did not speak directly to the client, which was sometimes experienced as inconvenient. An example that enhances this, is that the "main objective" of the client to use the model for use and maintenance was not known by some actors of the Dutch subcontractor. Language and hierarchy were given as a cause of this problem. However, coming together face to face was experienced as helpful in the communication. In the Dutch case, it is stated that BIM does not have the central role as a communication tool yet, that it could be. This is connected to the fact that people need to work in other ways, and sometimes go back to old, familiar ways of working.

During the design process, as stated by literature, the design and BIM model have to be reviewed. Looking at the corresponding validation and verification(RQ3), different parties in the process of the two observed cases use different ways of validating and verifying, which are connected to BIM in a greater or lesser extent. For example, designing parties use 3D clash detection to resolve design errors. The client has a more reviewing role, by means of making comments on the design, whether this is in 2D (Dutch case) or 3D (Foreign case). In the Dutch case, an internal validation takes places of around 20 people of the hospital.

In literature, reasons that influence the work process with BIM where amongst others communication of clear objectives, and skills of project actors. As mentioned by actors from both cases, the collaboration and work process(RQ4) are influenced by making (good) BIM agreements and actors skills and competences. Other things that can influence the work process are e.g.: changing ways of working and time pressure. Last, also language and culture can play a role in the work process, as well as in the communication. For example to which extent people can speak to, and understand each other, and how hierarchy influences the way actors work together.

The importance of the connection between the design and use phase is stressed by literature. However, in practice, the readiness for use(RQ5) of the BIM model is not yet established fully in both cases, because the models are currently still being developed. An important aspect in this subject, is the difference in needs for information from different actors, which can sometimes cause discussion.

Managerial implications

Below, recommendations are given for before, during and after the process of hospital building projects in which BIM is used, on basis of the critical points that can be of influence on the success of the process:

1) When initiating a project

It is important to invest in defining things upfront. When this happens well, time, money and difficulties can be saved in later phases.

a. **Why is BIM used?** Think about the way BIM is used in the project (also connected to 1b): Firstly why is BIM used: what are the goals and motives? And connect this to how to achieve this, and what kind of programs are suited. (see also 1.c) Different programs can work better for different projects.
b. **Interests and information needs:** Define the interests and information needs of different actors: this can differ for designing actors and for the client/end-users. Not everyone needs all the information from each other/in the model: e.g. the client may need installation components for maintenance, location, warranty details, or maintenance intervals, or may want to manage other parts.
c. **Structure, streamline and documentation:** think about the way building information is structured, streamlined and documented. For instance one big model instead of multiple models can be easy in adjusting things, but can become very heavy software. Different aspects can be made recognizable e.g. by different colours.
d. **Required skills/roles:** Think about which roles are needed: e.g. BIM managers, a data manager. Define the needed skills and competences in the projects, and look if these are available internally, can be trained internally, or need to be hired externally. The project manager should have BIM knowledge as well.
e. Involving stakeholders: BIM is not just a means to resolve design errors, but also a way to involve and work together with other stakeholders, amongst which the client. BIM can be used to work together in 3D, with all of the stakeholders: define if all actors are ready for working within BIM in a large extent. If not, look also at 1.g.
f. **Get to know each other:** Sometimes there are unequal expectations about the skills and competences of other actors: make sure people get to know each other and know what to expect from each other upfront (also connected to 2c).
g. **Training:** Training can be done by means of a pilot, workshops, or example models, or even by innovative ways such as serious gaming.
h. **Think about the points of 2** (during the project) upfront.
i. **Invest in BIM:** Invest enough time and money into the implementation of BIM, check if changes have to be made in the organization/way of working.
j. **Agreements:** Make good agreements about the way of working in the project, connected to the points of 1 and 2.

2) **During the project**

It is important to keep steering on things during the project, to prevent or resolve issues.

a. **Incidents:** The successful implementation of points of 1. can be influenced by incidents in the process: such as time pressure, and changing ways of working which people need to get used to: define these incidents and steer on them.
b. **Agreements:** Stick to agreements, and if incidents in the process depend otherwise: discuss together how to work further in the project, not losing sight of why choices in 1. are made at first.
c. **Enhance collaboration:** To enhance collaboration and communication, people should come together face-to-face (internally and externally) every now and then, although this can be influenced by language and hierarchy. Organize face-to-face project (and other) meetings.
d. **Keep communicating** about things that come up during the project.
e. **New BIM programs & training:** When new programs are implemented during the process, it can help to train people about the new program, or with (pilot) examples, or other ways of training (see also 1.f).
f. **Reflect:** reflection does not have to happen only after the project, it can be done during the project as well, to evaluate what happened and steer further during the project and its process.

3) **After the project:**

Reflection after the project can be of help for future projects.

a. **Reflect**: on the process to improve future projects, considering the above-mentioned aspects and other things that come up during the process.

4) **Possible implementations for the future, limitations and future research**

The following are possibilities for the future that should be investigated further.

a. **BIM goals and use of BIM:** from the research, it became clear that the goals of BIM are not always clear, for organizations themselves, as well as for other actors. It could be investigated further what the goals of different actors are, why to use BIM, and how they consequently use it.
b. **Involving the client:** The potential of BIM is not just a tool for design and maintenance, but also to involve the client and end-users early in the process. It should be taken into account which information should be shared with the client, because the client and end-users will have their opinion and expectations, and may not have extensive building-technical knowledge. More research could be done on how to involve them and what their interest are.
c. **Skills&competences and roles:** Different skills and competences are needed because of BIM, thus new professions arise: next to BIM modelers, managers and coordinators, also data managers, or project managers with more knowledge of BIM → It could be investigated further what roles are needed and what they need to be exactly. The usability of BIM programs for different

project actors and different (innovative) ways of training people with BIM can be investigated. It can also be investigated on a bit higher level, which party in the project (design team actors, client) should have which knowledge.

d. **Responsibility and BIM management:** connected to b, is the fact, which actor(s) or party (or parties) has/have the responsibility for the implementation of BIM and/or does the BIM (process) management. Further research on this can be done as well.
e. **People vs Software:** There can be a mismatch between the usability of programs, and the way how people work, and what their knowledge and skills are: a way to improve this could be better training in education, internal training inside companies, and better information or trainings from program makers about how to work with these programs.
f. **Extensive applications:** In the future, BIM could have more extensive applications, for instance as a means next to (or even instead of?) 'mock up' (test) rooms. Other current innovations are e.g. virtual reality glasses, to really walk through a space in 3D. More research could be done on how to implement these applications.
g. **Transferability:** In this research, only two hospital cases are investigated, one in the Netherlands, and one Foreign case. In order to verify the transferability to other projects, the research could be broadened by investigating more cases in and outside the Netherlands, as well as by investigating other types of building projects.

All and all, many possible improvements can be made in (future) building projects. Although the former forms a list of recommendations for (future) projects, it should be taken into account that BIM is, and most probably stays in development, and programs and tools improve continuously. This innovation may bring future possibilities and also new challenges, which are not always predictable. Former means that continuous research is inevitably, however, beforementioned recommendations can be used as a current "best practice".

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8. Appendices

A. Case context

A.1 Dutch case – elaborated case context

A1 – Dutch case - Extensive case context

A.1.1. Contractual relationships

Figure A.1.1 shows the contract form of the project. All parties are Dutch.

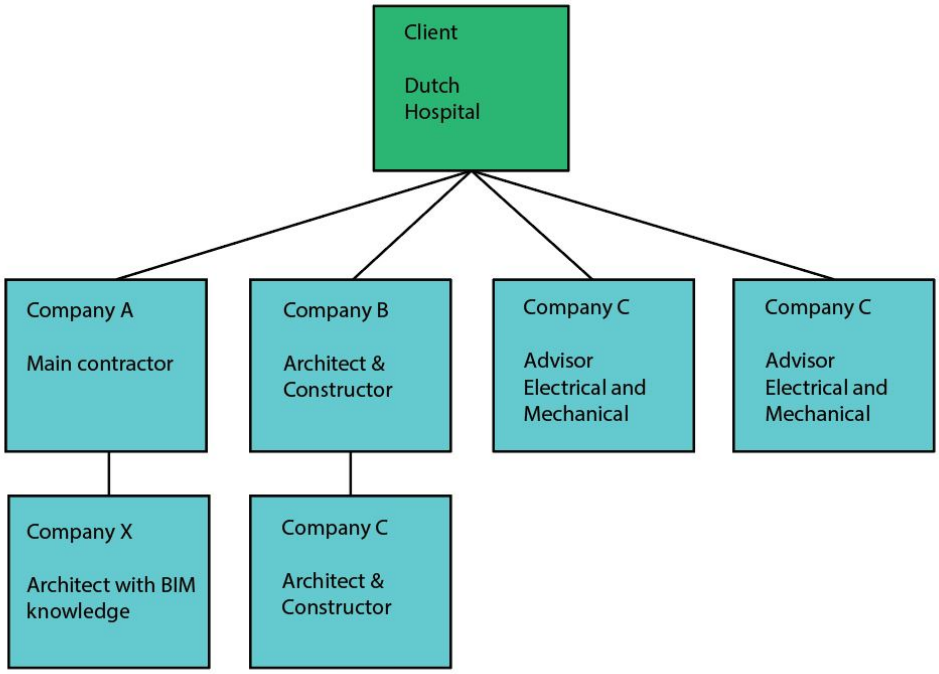


Figure A.1.1. Contract form Dutch hospital case. (Scheme on basis of BIM execution plan page 6 and interview Project manager, personal communication, April 10, 2018)

A.1.2. Implementation of BIM in the organization

Figures A.1.2 and A.1.3 show the implementation of BIM in the building process. Figure A.1.2 shows that BIM is used in a cyclical way, and figure A.1.3 shows that the hospital thinks about the process from initiative until delivery for operation and maintenance.

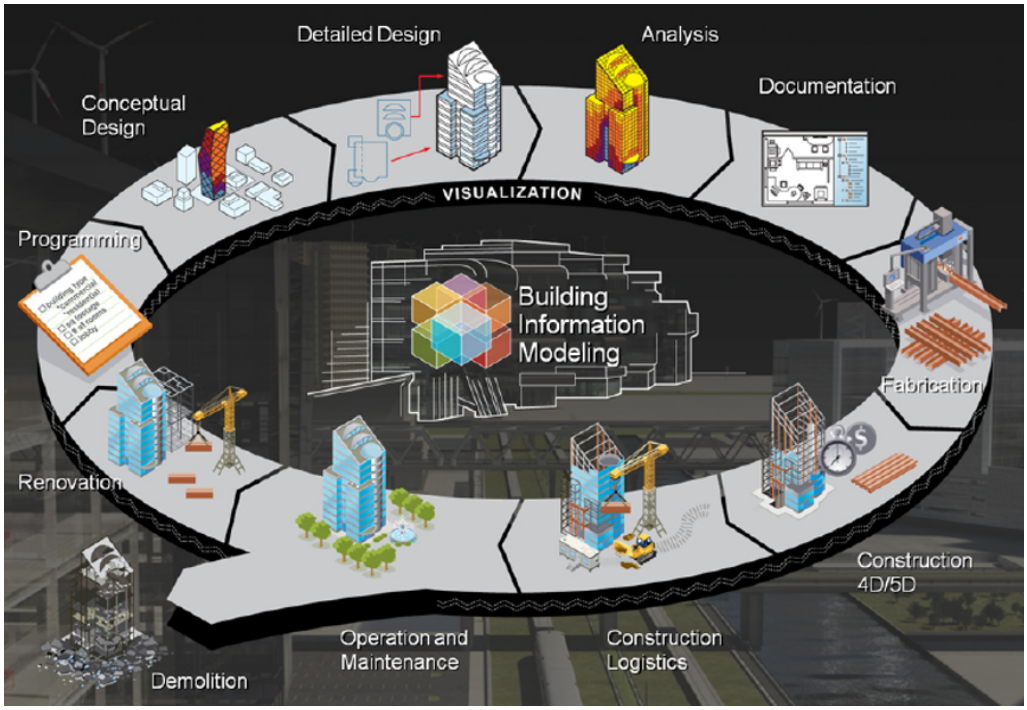


Figure A.1.2. Cyclical use of BIM in the process.

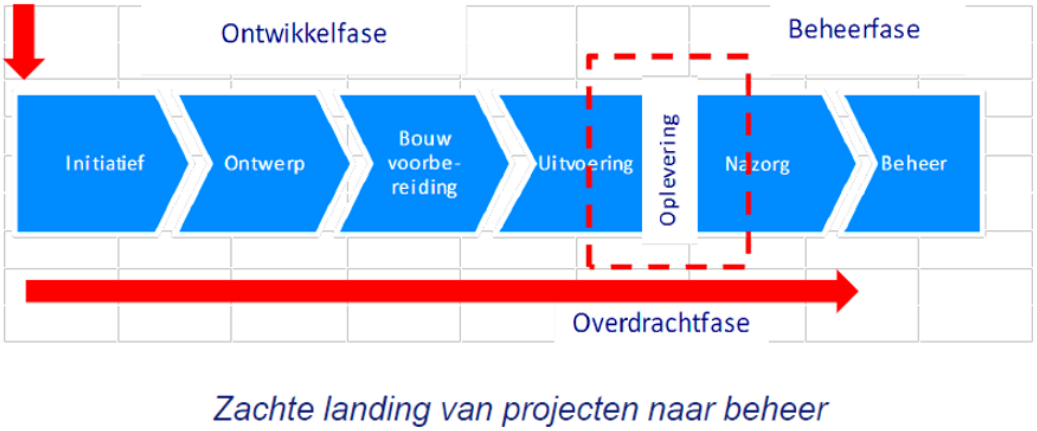


Figure A.1.3. From initiative to delivery for operation and maintenance.

A.1.3. Organization of BIM roles

The organization of BIM roles can be found in figure A.1.4. According to the central information manager, the roles of BIM director and Project manager in the first image should change place: the project manager should have BIM skills and be more at the centre of the process. (Central information manager, personal communication, November 10, 2017)

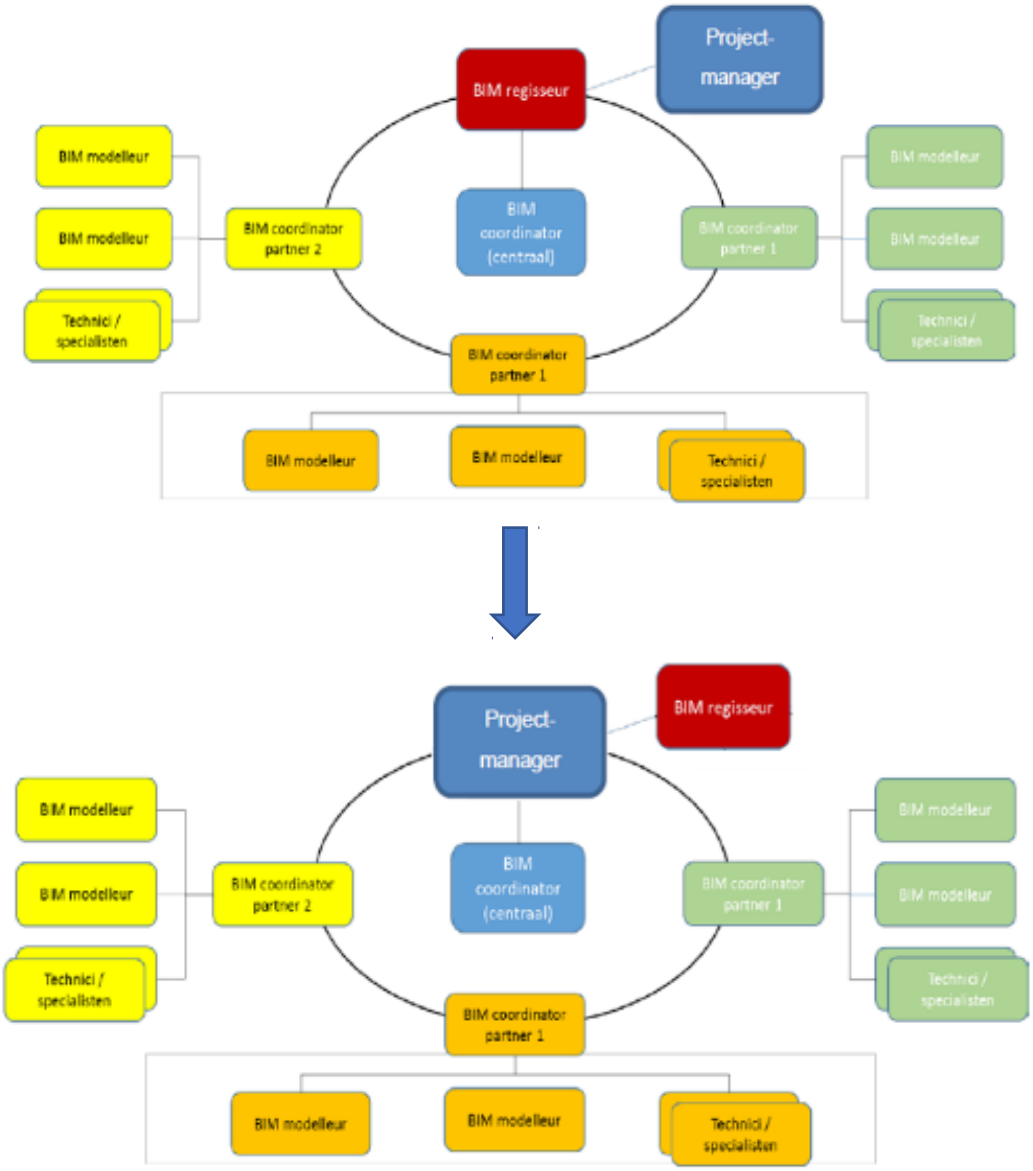


Figure A.1.4. The organization of BIM roles. The project manager and BIM regisseur should change location. (Above: Image from BIM presentation; and below: adjusted image of the presentation on basis of interview central information manager)

A.1.4. BIM vision and explanation

The hospital uses its own BIM protocol, with a BIM vision. De core points from the BIM vision are:

1. The building data should exist and be useable as long as the building exists.
2. Make use of open BIM, unless this is not possible (see explanation)
3. If open BIM is not possible, use of source data
4. In case of 2 and 3 are not possible because of required drawings or calculations, use of (2D) CAD
5. Working from course to fine with level of detail (see explanation)
6. An interim structural division of information and evaluation takes place

7. An open data structure is used

Explanation - 2&3. Open BIM: An open BIM standard is used following the international standards of BuildingSMART (www.buildingsmart.org). The main principles of Building smart are:

1. BIM processes (IDM: information delivery manual)
2. BIM object libraries (IFD: international framework for dictionaries
3. BIM models (IFC: industry foundation classes)

IDM and IFD are not yet often used in the Netherlands, so they are not (yet) necessary.

Project information should be consistent and coherent. This means that the models are integrated and aligned together. The objects should have relevant connections, are unambiguous and identifiable.

Explanation 5. BIM & LOD: The way of working is often "from course to fine". There is not one standardized form, the hospital uses the following principle:

They use as a growth model for the level or detail in the project, that the project and building information start from the spatial functional- and technical requirements. During the development and realization of the project, it is elaborated to the required detail level for each phase.

The following LOD in used in the project:

VO: LOD 100, DO: LOD 200, TO: LOD 300 (all building parts), only for mechanical air installations, and electrical parts LOD 400 in UO. (Bijlage 2 BIM uitvoeringsplan)

A.1.5. BIM information level

In figure A.1.5. and A.1.6. below, the red line shws the practical outcome of BIM information development. (Centrale informatiemanager, 2017; Constructeur, 2017)

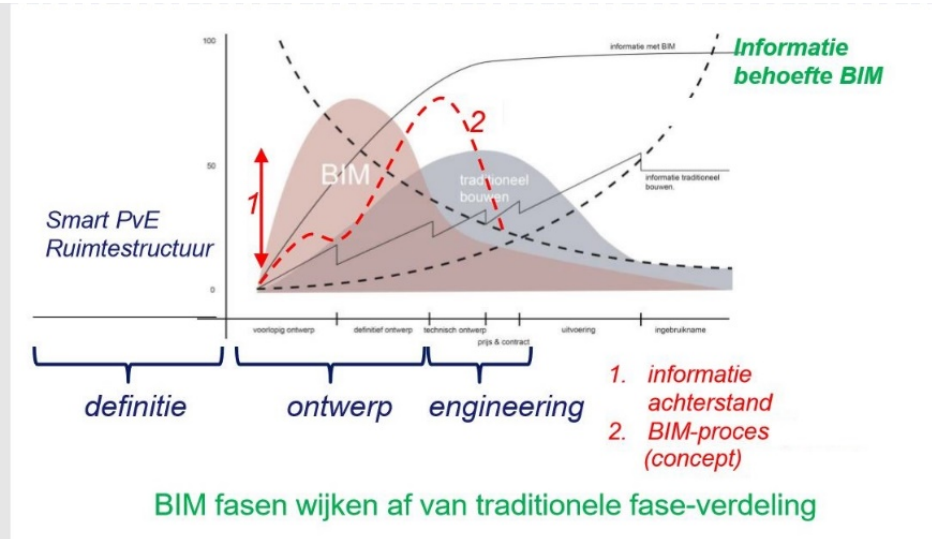


Figure A.1.5. Information development with BIM, in theory and practice.

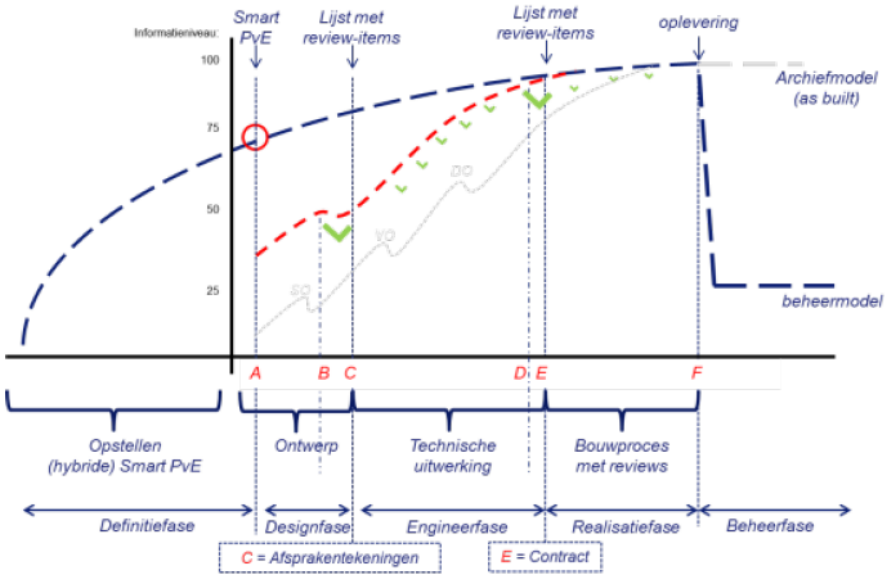


Figure A.1.6. Information development with BIM. (Presentatie BIM project&beheer, 2017)

A.1.6. ILS

Retrievable from:

Dutch version: http://bimloket.nl/upload/documents/downloads/BIMbasisILS/BIM%20basis%20ILS%20(A4).pdf

Last retrieved 24/05/2018

English version:

http://bimloket.nl/upload/documents/downloads/BIMbasisILS/BIM%20basic%20IDM%20(A4).pdf

Last retrieved 24/05/2018

A.2 Foreign case – elaborated case context

A.2.1. Contractual relationships in the project

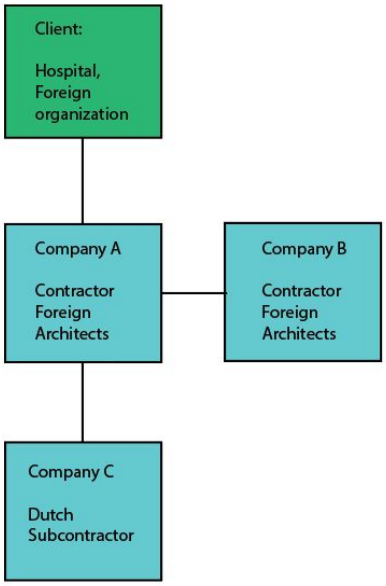


Figure A.2.1: Contract form of the project. (Scheme on basis of Interviews Project director; Project manager)

A.2.2. Detailed description of project goals

"Optimal coordination per design discipline
The coordination of various aspects of a specific discipline that are handled in one or multiple models, and potentially
by multiple parties.

Optimal coordination between design disciplines
The coordination of the various aspects of the various disciplines that are handled in multiple models, and often by multiple parties.
The integral assembly into one model of these various aspect models at regular intervals (there is no Revit/BIM server), so that the common ground of the various disciplines can be coordinated regularly/synchronously during the development of the design (time according to agreement – see further).

Optimally coordinated 2D/3D output
Working optimally coordinated within 1 discipline and 1 integral discipline model ensures unambiguous information in
a 3D model and consistency in the 2D plans derived from the model.

BOQ – 'Specifications'
The model represents the exact amounts of building materials and equipment, needed in the building.

Visualization for client and users

To present the design in such a manner the clients and users get a good impression of the various aspects of the
design that are relevant to them, such as use, appearance, experience… This within Revit's basic presentation
functionalities. This is about functional visualization, not presentation images or photorealistic representations."

A.2.3. - Full definition of roles

"**BIM Information Manager/BIM Director**

The BIM Information Manager takes a directing role as independent advisor in carrying out the interdisciplinary BIM design and execution process and is mandated by the client for this purpose. The BIM Information Manager falls within the competence of the client's project manager. The BIM Information Manager directs and monitors the BIM team during the execution of the BIM Execution Plan2.

None of the activities included in the role of 'BIM Information Management' refer to design responsibility. However, the role of BIM Information Manager can be performed by a project team member with design responsibility, such as the Design Team Leader or the prime contractor (although this causes the independence mentioned in the previous paragraph to expire – the property developer/building owner decides)

BIM Manager

Aside from a BIM Information Manager who stands next to the property developer/building owner, every company that participates in the BIM process for the project also has a private BIM Manager, and every company also has BIM coordinators per project.

The BIM Manager carries out tasks that are similar to those of the BIM Information Manager, but on the company's level and for various BIM projects.

BIM Coordinator (Management)

This management function is project and BIM specific. Every project needs a coordinator that is responsible for the start-up of the project, the auditing of the model and the coordination with all collaborating parties (up = with the BIM Manager/Information Manager and down = with the modellers). A Coordinator can manage multiple projects, but must stay available to intervene when necessary during the entire trajectory.

BIM Modeller (Production)

The BIM Modeller takes care of the production of the models. For bigger projects, multiple modellers will be deployed simultaneously. BIM experience is not necessary, however technological skills are a necessity (know your software and all its possibilities).

Any specific allocation of tasks or changes in 'Role' descriptions will be further described in the BIM Execution Plan."

(BIM protocol Foreign case)

A.2.4. Responsibilities of different parties

Responsibilities Company A

Number	Article		phase DETAILED DESIGN (aanbesteding)
02 - GRONDWERKEN EN BIJZONDERE FUNDERINGEN			
	Beschoeiingen		200
	Funderingspalen en structurele ankers		200
03 - OPEN RUWBOUW			
3.03	ELEMENTEN UIT TER PLAATSE GESTORT GEWAPEND BETON		
	Ter plaatse gestort gewapend beton		300
		Funderingen	
		Kelderwanden	
		Kolommen en wanden	
		Balken	
		Platen	
	Ter plaatse gestort architectonisch beton		300
3.05	ELEMENTEN UIT GEÏNDUSTRIALISEERD BETON		
	Elementen uit geindustrialiseerd beton		200
		Kolommen	
		Wanden	
		Balken	
		Trappen, bordessen	
	Geprefabriceerde elementen uit spanbeton		200
		Balken	
		Liggers	
		Vloerelementen	
	Geprefabriceerde elementen uit architectonisch beton		200
3.05	ELEMENTEN UIT GEÏNDUSTRIALISEERD BETON		
	Breedplaatvloeren en druklagen		200
		Breedplaatvloeren	
		Druklagen	
3.06	STALEN STRUCTUURELEMENTEN		
	Structureel profielstaal		300

Responsibilities Company B

Number	Article		phase DETAILED DESIGN
			(aanbesteding)
10 - Architectuur			
10.00	Algemeen		0
10.01	Sloop		200
10.02	Grondwerken		200
10.03	Open ruwbouw		
		structural elements	modelled by structural
		non-structural elements	300
10.04	Renovatie		300
10.05	Daken		300
10.06	Riolering		200
10.07	Gevelsluiting		300
10.08	_		
10.09	Vloerbekleding		200
10.10	Binnenschrijnwerk		200
10.11	Verlaagde plafonds		200
10.12	_		
10.13	Vast meubilair		100
10.14	_		
10.15	Schilderwerk		0
10.16	Omgevingsaanleg		200
10.17	Groenaanleg		200
10.18	Los meubilair		100
10 - MEP			
	Toestellen sanitair		100 + extra data
	Toestellen HVAC		100 + extra data
	Toestellen elektriciteit		100 + extra data
	Toestellen liften		100 + extra data
	Toestellen grootkeuken		100 + extra data
	Toestellen medische gassen		100 + extra data

20 - FINISHING		
20.09	Vloerbekleding	300
20.1	Binnenschrijnwerk	300
20.11	Verlaagde plafonds	300
20.12	_	
20.13	Vast meubilair	100
20.14	_	
20.15	Schilderwerk	0
20.18	Los meubilair	100
20 - MEP		
	Toestellen sanitair	100 + extra data
	Toestellen HVAC	100 + extra data
	Toestellen elektriciteit	100 + extra data
	Toestellen liften	100 + extra data
	Toestellen grootkeuken	100 + extra data
	Toestellen medische gassen	100 + extra data
30 - INTERIOR		
30.13	Vast meubilair	200
30.14	_	
30.18	Los meubilair	200

Responsibilities Company C

Number	Article	phase DETAILED DESIGN
Plumbing		
	Drainage	
	Sanitary Sewerage (Grey- , black-, grease-, hydrocarbon-water)	
	Stormwater Drainage (Rainwater)	
	Mechanical Equipement (Storage tanks, grease trap, hydrocarbon trap, pumps.....)	200
	Mechanical Equipement (storage tanks; pumps ; ...)	200
	Pipes & Pipe Fittings	200
	Pipe accessories (Supplementary components)	100
	Combustion gases evacuation (Chimneys)	
	Ducts & Fittings (Chimneys)	200
	Pipe accessories (Supplementary components)	100
	Supply (Water, Fuel)	
	Cold -, hot -, fire -, treated -, proces water, fuel	
	Mechanical Equipement (storage tanks, pumps, sanitary boiler, watertreatment ...)	200
	Pipes & Pipe Fittings	200
	Pipe accessories (Supplementary components)	200
	Mechanical Equipement: endunits	100
	Gas Supply	
	Mechanical Equipement (meters, storage tanks, ...)	200
	Pipes & Pipe Fittings	200
	Pipe accessories (Supplementary components)	200
	Mechanical Equipement: endunits	100
HVAC		
	Cooling/Heating/Combined systems	
	Mechanical Equipement: central (production):	200
	cooling units; surge tanks, drycoolers...	
	boilers; combined heating and power, heat pumps, ...	
	heat pumps, VRV,...	
	Pipes & Pipe Fittings	200
	Pipe accessories (Supplementary components)	200
	Mechanical Equipement: endunits	100
	cooled ceilings, convector,...	
	radiators, convector,...	
	fancoil,..	
	Ventilation (Air treatment)	
	Mechanical equipment central (fans, air handling units, ...)	200
	Ducts & Fittings	200
	Duct Accesories (VAV-boxes, dampers, filters, ...)	200
	Air terminals: (air diffusers, fancoil; .....)	100
Electrical installations		
	Power distribution	
	High Voltage & Emergency power distribution	
	Love voltage distribution	
	Electrical Equipment (meters, transformer, generator set, cabinets, UPS...)	200
	Cable trays	200
	Devices (high voltage cabinets, outlets...)	100
	Lighting	
	Electrical Equipment (cabinets;...)	200
	Cable trays	200
	Devices (switches,...)	100
	Lighting fixtures	100
	Weak current installations	
	Communication installations	
	Safety installations	
	Electrical Equipment (cabinet;...)	200
	Cable trays	200
	Devices (data; COAX; videophone; firedetectors, camera,...)	100

A.2.5. use of models and naming models

The following rules about using models are stated in the BIM execution plan:

"As everyone will be using models of another party as a reference, it is important to build up and preserve a good neighbourly relationship with open communication
Therefore, hereby some rules:

- It is forbidden to edit the aspect model of another party.
- It is forbidden to rename or delete (from Buzzsaw) the aspect models, not even your own models, without consulting the BIM Information Manager.
- It is forbidden to forward models to third parties without prior consent of the BIM Information Manager.
- It is advisable to communicate proactively about errors that are noticed in the models of other parties
- When in doubt, it is advisable to communicate directly with the modellers of other parties.
- It is mandatory to 'co-operate'!!

Aspect models are linked together through the '***Linked Files'*** function in Revit. Thus, a complete model is put together" (BIM execution plan, final version, 2016, p 33)

Naming models

The following rules are given in the BIM Execution plan on naming models:

The different models, aspect models and sub-aspect models receive an unambiguous name that is clear and understandable for all parties at all times.

This name may not be changed without consulting with the other parties and without consent by the BIM Information Manager. This is in connection with the links that are made by the other parties according to this model name.

Models have a uniform nomenclature. This name does **not** change during the project. The name is based on the decomposition of the project. The models have to be put on Buzzsaw by the name established here. The nomenclature for internal use in the company can be chosen freely.

However, when models become too massive and they need to be divided, a new name must be agreed upon with the BIM Information Manager. This modification must be communicated to all parties ASAP.
The project number of the company is NOT added to the file name, as this is not relevant for the other parties and this disrupts the 'format'.

The name of the '***central' file*** is the same as the file name mentioned above.
The name of the ***'local' file*** is generated automatically.

Table 5 - Format File Naming

Discipline	Company	Building n°	Building part	2nd Building part (optional)
ARCH	COMPANY X	BU1	LOT2	FAC

Figure A.2.2: Procedure of naming models. (BIM execution plan, page 38)

A.2.6. Level of Development

Table 7 shows when which level of detail is implemented by which party in the project during the detailed design phase.

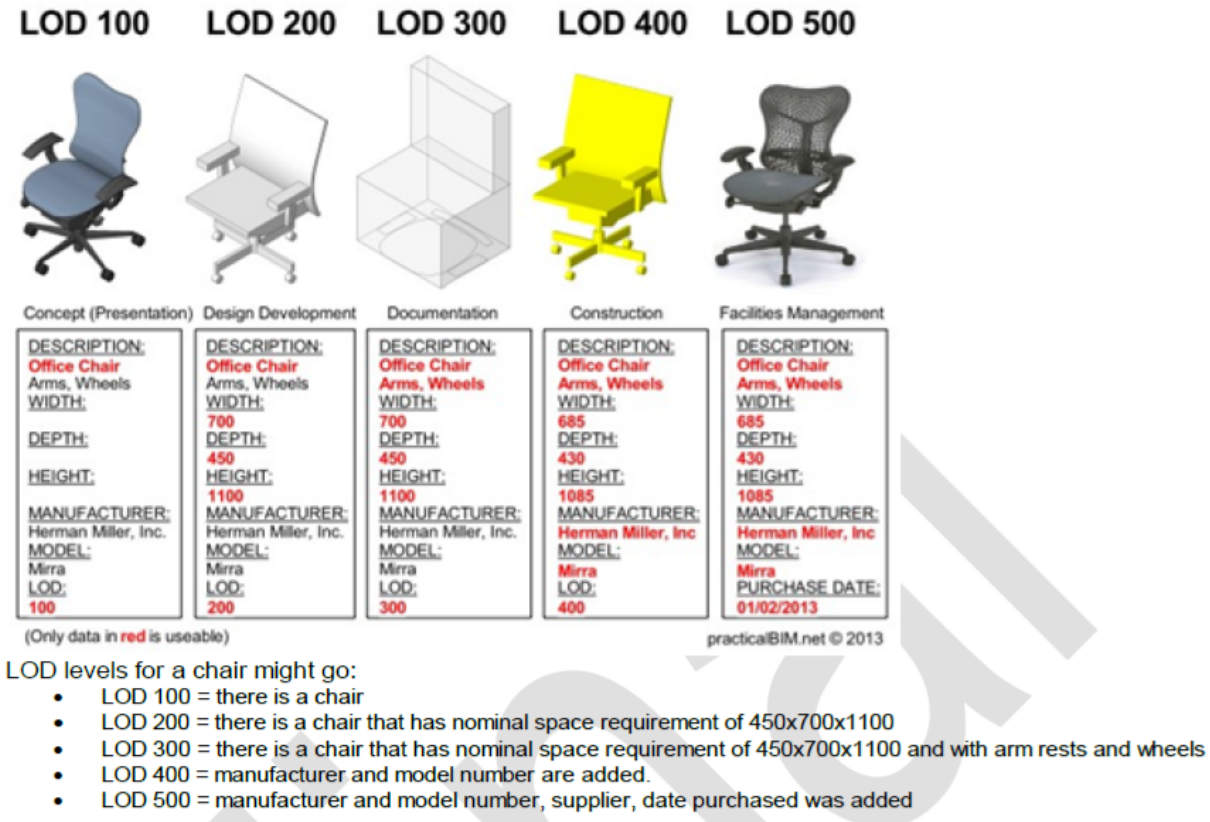


Figure A.2.3. Explanation of level of development. (BIM execution plan, p 23)

A.2.

Procedure:

Review procedure on DWFx files:

"2.1 Controller:
1. The Controller makes a copy of the DWFx bundle.
2. The Controller opens this copied DWFx bundle in Design Review.
3. He indicates de remarks with clouds and numbers in the DWFx.
4. He puts the remark text itself under 'New Note' when selecting the placed cloud.
5. Next, an email is sent to the Author of the DWFx bundle AND to the generic email address of the discipline.
For the complete and detailed procedure see DWFX REVIEW PROCEDURE on page 16.

2.2 Author:
▪ The author analyses the remarks:
o Reads the remark in Excel or Revit
o He performs the adaptation or solves the problem in Revit and sets the status of the remark to 'Done'.
o In case he cannot solve the problem himself he should contact others to have this problem solved by the due date. As long as the problem is not solved, the status cannot be set to 'Done'!!
▪ Sends a notification of the status to the Controller AND to the generic email address of the discipline.
For the complete and detailed procedure see DWFX REVIEW PROCEDURE on page 16.

2.3 Controller:
Next, the Controller checks the status (remark, question etc.) and gives the "go" for 'delivery'.
Only when all remarks are set to 'Done', the document can receive a 'go' for delivery.
Again he needs to send an email to the generic email address of the discipline to notify all."
(BIM execution plan, 2016, p. xx)

A.2.4 – DWFx Review procedure

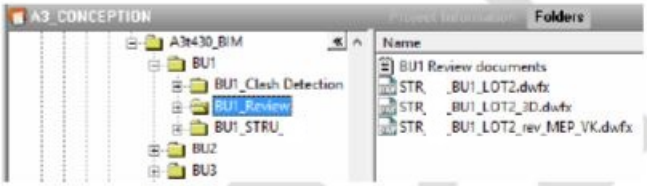
Review all DWFx plans "Digitally" in *Autodesk Design Review*. This way everyone can review the model and give their remarks on the same DWFx bundle on a regular base by using the Buzzsaw platform.

Remark:
You can open and review DWFx files on Buzzsaw too by using '*View in Window*', but we advise using the '*Edit* procedure as set here as it is much safer and more straight forward.

1. Opening the DWFx file

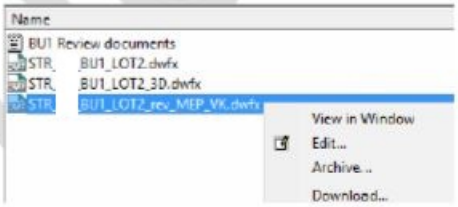
1.1 On the due date the author of the model has placed his DWFx bundle on the correct location on Buzzsaw.

1.2 You as a controller start the control by copying this file (in the current location on Buzzsaw) and add your 'Company ID' to the file.



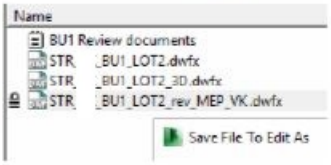
1.3 Next, select this DWFx file (as it is a bundle it holds several sheet views).

1.4 Right mouse click, Edit….



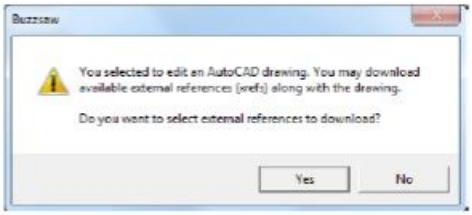
1.5 Buzzsaw will automatically 'lock' the file on Buzzsaw so nobody else can edit it.

1.6 Buzzsaw will ask you to temporarily save the file on your computer. (Remove afterwards! Only version on Buzzsaw is ruling!)



1.7 Click 'Save'

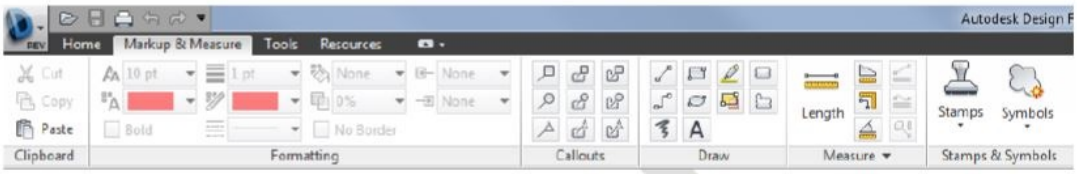
1.8 When Buzzsaw asks:



1.9 Click no, as a DWFx file does not have xrefs.

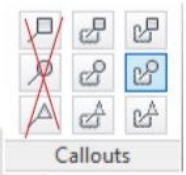
1.10 Design Review5 will open on your Computer with the selected file active and you can start checking and adding mark-ups.

2. Making remarks – Adding Mark-ups



2.1 Add Mark-up

Remark:
Only Callouts with label are allowed.



2.2 Use **your** correct colour:

Colour[6]	Number range	Remark from
	0000 - 1999	
	2000 - 3999	
	4000 - 5999	
	6000 - 7999	
	8000 - 9999	

Use correct leading letter!!

2.3 Fill out the label with a number:

Number	Remark addressed to
A_XXXX	
S_XXXX	
M_XXXX	
E_XXXX	
F_XXXX	

2.4 When callout and number was added, don't forget to fill out the 'New Note' box to explain what the remark is all about.

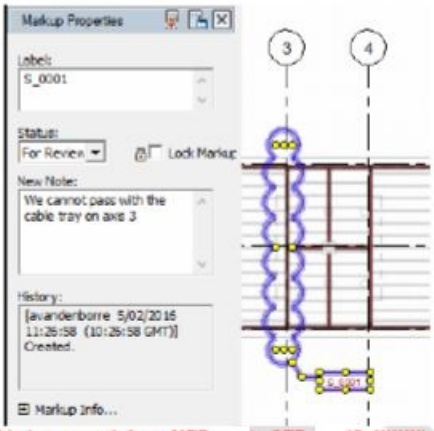
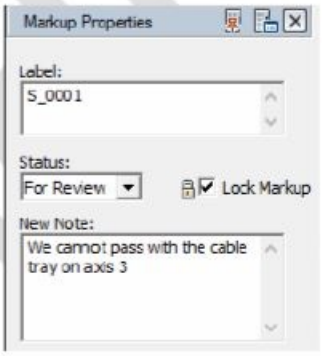


Figure 3 - This is a remark from MEP_ to STR_ (S_XXXX)

2.5 Set the status:

2.6 Lock Mark-up

Lock the mark-up so it can't be deleted.



Remarks:

- Use English in the mark-up labels so everybody can understand your issues.
- You can see at all times the Review History of each cloud.
- The text in the 'Label' window will be visible on the sheet, the text in the 'New Note' window will not be visible on sheet and the status will be visible as it sets different colours to different states.

2.7 Create a Mark-up Summary

When you finished adding mark-ups, you should make a mark-up summary. This is an excel list showing all mark-ups, listed by number and status. The comment, history and creator identity are also added. How to do this is explained in CREATE A MARK-UP SUMMARY on page 19.

2.8 Closing the DWFx

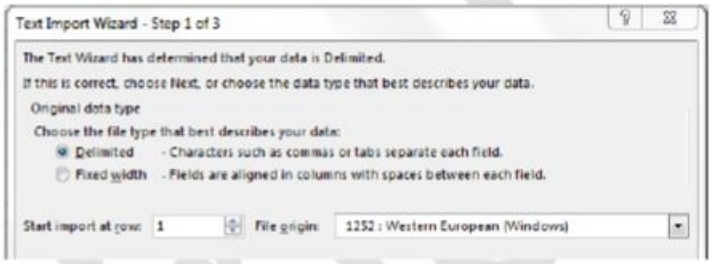
Close the DWFx file in design review when you are finished adding mark-ups by Clicking 'Save' and 'Close 'Design Review (yes, the whole program). Now the file with remarks will automatically be uploaded to Buzzsaw and the file will get 'unlocked'.

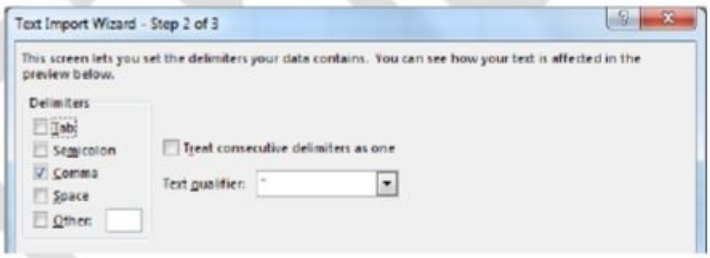
3. Create a Mark-up Summary

3.1 You can create a list with all Mark-ups and their status and information by selecting 'Saving Mark-ups Summary' in Design Review:

3.2 A CSV file is created.

3.3 You can open this file in Excel using the following settings:





3.4 Now a list of all the mark-ups and their status is available in Excel.

	A	B	C	D	E	F	G	H
1	Sheet		Markup type	Markup label	Markup text	Creator	Created	Status
2	Sheet: 04.0 - FP60_040_A0_100		Rectangle Callout, Revision Cloud	A_Finished floor thickness?	A_Finished floor thickness?			Done
3	Sheet: 04.0 - FP60_040_A0_100		Rectangle Callout, Revision Cloud	G_grid names	G_grid names		28/10/2013 15:58:43 (14:58:43 GMT)	Question
4	Sheet: 04.0 - FP60_040_A0_100		Rectangle Callout, Revision Cloud	G_test	G_Test		28/10/2013 16:31:24 (15:31:24 GMT)	<None>
5	Sheet: 04.0 - FP60_040_A0_100		Rectangle Callout, Revision Cloud	S_Column dimensions	S_Column dimensions			Done

3.5 Save this file as an excel file using ".xlsx".

3.6 Add this list to Buzzsaw (same location as DWFx bundle)

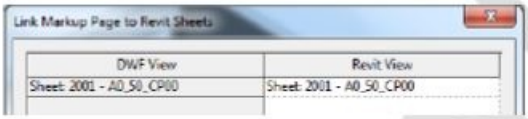
Remark:
You can create these summaries at any time to check the status of the remarks.

4. Processing remarks - Mark-ups

When the controllers have checked your files, you will see a couple of copies of your DWFx bundle with the name of the 'controlling' party added at the end. Now you can start processing your remarks.

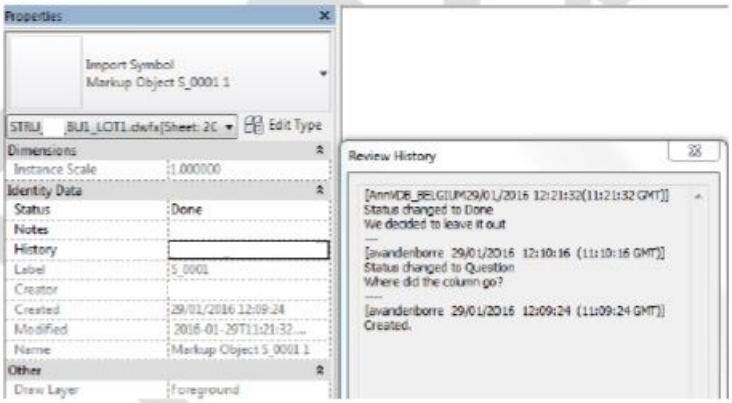
4.1 Download the DWFx bundle with remarks from Buzzsaw.
4.2 Lock the file on Buzzsaw7
4.3 Open your Revit project.
4.4 Link the DWFx mark-up file bundles into you Revit project (you can add several at the same time)

4.5 Revit will ask if sheets correspond:



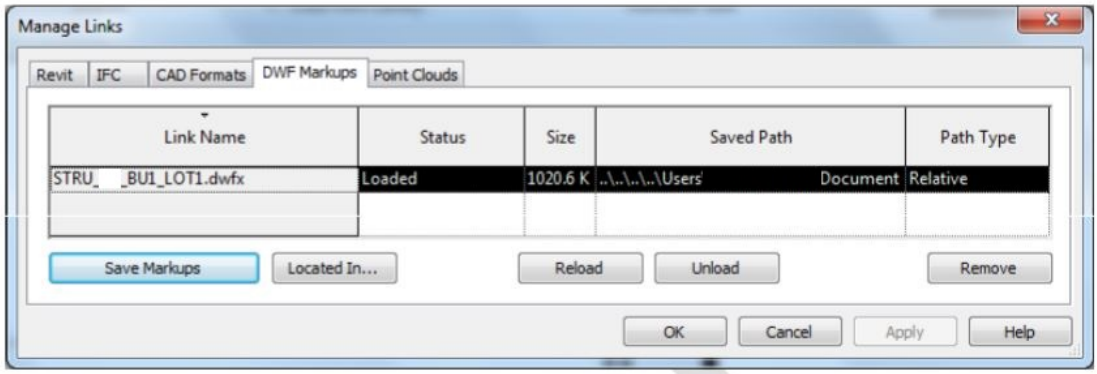
4.6 Open the sheets and look at the mark-ups

4.7 Select the mark-up and check the properties.
In Revit you can read the notes from others by opening the 'History'. (or you read it in the Mark-up summary you can create in excel.)



4.8 Make the necessary changes and/or answer the questions.
a. Make the necessary changes
b. Change the status
c. Add Notes if necessary
d. You can see at all times the Review History of each cloud.

4.9 When finished answering the remarks, don't forget to save your answers and remarks by going to 'Manage links', tab DWF Mark-ups:



4.10Click 'Save Mark-ups'.
4.11Remove the DWFx link
4.12Upload your DWFx file with added comments to Buzzsaw.
4.13The file will automatically get unlocked.

Overall DWFx Remarks – IMPORTANT!!

When using DWFx files please make clear to observe the following rules:

- Do not scale the dwfx print since this will also reduce the size of the comments
- Comments should stay within the border of the sheet otherwise they are not visible in Revit
- De originator of the comments should check that these have been dealt with after getting a signal that the clash is resolved and put the comment to 'Done'.

Figure A.2.4: Detailed DWFx review procedure. (BIM execution plan, 2016, final version, p 16-21)

Appendix B – Interview for project stakeholders

The interview is held as a semi structured interview. For the foreign stakeholders, this interview is used as a questionnaire.

B.1. Nederlandse versie / Dutch version

Dit interview bestaat uit een inleiding, relevantie, doel van het onderzoek, hoofdvraag, deelvragen en interview vragen.

Inleiding van het onderzoek

Het onderwerp van dit onderzoek is **validatie en verificatie** van het **ontwerp van ziekenhuis** gebouwen, tussen het **ontwerpteam en de client/eindgebruiker**, terwijl er wordt gewerkt met **BIM** (Building Information Modelling).

Ziekenhuisgebouwen zijn complexe gebouwen, welke door hun technische complexiteit, en het aantal stakeholders, volgens onderzoek goed passen bij het gebruik van BIM. Building Information Modelling (BIM) zijn 3D programma's en digitale tools voor visualisatie en informatie management waarmee gebouwen kunnen worden ontworpen en beheerd. Verschillende project stakeholders kunnen samenwerken in BIM.

Validatie van het ontwerp betekent dat het ontwerp of BIM model aan de gevraagde functionele eisen voldoet, verificatie betekent dat het ontwerp correct is en de BIM op de juiste manier is geïmplementeerd.

De relevantie en het belang van dit onderzoek liggen in het feit dat er in de literatuur, en ook in verschillende eerder gehouden interviews, wordt vermeld dat de communicatie met BIM nog steeds een kritiek aspect is in complexe projecten zoals ziekenhuizen. Ook komt voort uit de interviews dat BIM nog niet altijd werkt zoals vanuit de literatuur en programmamakers wordt voorgesteld. Ten eerste is er niet altijd een goede communicatie met BIM tussen de verschillende stakeholders, ten tweede hebben project actoren niet altijd de juiste vaardigheden, en ten derde is de aansluiting met BIM tussen het ontwerp en het gebruik/beheer van het gebouw vaak te zwak aanwezig.

Het doel van dit onderzoek is daarom om meer inzicht te krijgen in – en zo mogelijk het verbeteren van – de processen van communicatie tussen verschillende stakeholders die werken met BIM. Meer specifiek zal er gekeken worden naar het valideren en verifiëren van het ontwerp met behulp van deze BIM. Ook zal er gekeken worden naar hoe er tijdens het ontwerp rekening wordt gehouden met de gebruik&beheerfase van het gebouw.

De hoofdvraag luidt: op welke manier is de functionaliteit van het ziekenhuis tijdens de ontwerpfase gevalideerd en geverifieerd tussen de project stakeholders, welke samenwerken in BIM, en hoe wordt er hierbij rekening gehouden met benodigde informatie voor de gebruik&beheerfase van het gebouw.

De bijbehorende **deelvragen** zijn ***(optioneel beantwoorden in plaats van gehele enquete, gehele enquete hierna)***

1) *Tot in hoeverre/op welke manier wordt BIM gebruikt in de ontwerpfase van dit ziekenhuis als een middel om informatie uit te wisselen tussen het ontwerp team en de klant/eindgebruikers van het ziekenhuis.*

Uw antwoord…

2) *Hoe wordt het ontwerp gevalideerd en geverifieerd tussen de verschillende partijen, en hoe wordt BIM hierin gebruikt (bijvoorbeeld Dalux, Revit..): tussen de ontwerpende partijen, als wel als met de klant/eindgebruikers.*

Uw antwoord…

3) *Tot in hoeverre is er een goed functionerende communicatie/informatie uitwisseling tussen de verschillende partijen, en goed functionerend BIM model?*

Uw antwoord…

4) *Tot in hoeverre/op welke manier beïnvloedt het gebruik van BIM de samenwerking en het werkproces (positief/negatief)?*

Uw antwoord…

5) *Tot in hoeverre is de BIM bruikbaar voor de cliënt tijdens de gebruik&beheerfase? (Vooruitkijkend)*

Uw antwoord…

Interview vragen voor de verschillende stakeholders:

Dit interview bevat vragen voor het ontwerpteam en vragen met betrekking tot eindgebruikers.

1a) Vragen voor actoren van het ontwerp team

1. *Wat is uw rol /bijdrage in het project? Hoelang werken de project teamleden al samen, en werken ze vaker samen met deze partijen?*

Uw antwoord…

2. *Hoe zit de contractvorm in elkaar van het project?*

Uw antwoord…

3. *Hoe werkt u met BIM in het project?*
    a. *Wat is uw definitie van BIM?*
    b. *Op welke manier maakt u gebruik van BIM?*
    c. *Hoe communiceren jullie met BIM?*
    d. *Tot in hoeverre worden de project documenten gevolgd: BIM protocol, uitvoeringsplan etc.*
    e. *Is dit gebruikelijk vergeleken met andere projecten?*

Uw antwoord…

4. *Maken alle project partners gebruik van BIM?*
    a. *Hoe zijn uw/hun vaardigheden met BIM?*
    b. *Hebben u/ze vaker projecten met BIM gedaan?*

Uw antwoord…

5. *Waar bevind het BIM model zich, centraal beheerd of in afzonderlijke delen?*

Uw antwoord…

6. *Heeft BIM een toegevoegde waarde voor de samenwerking/het werkproces?*

Uw antwoord…

7. *Hoe wordt de functionaliteit van het ontwerp gevalideerd en geverifieerd (zie toelichting in introductie) tussen de partijen?*
    a. *Intern (Revit, dalux, briefbuilder..?)*
    b. *Tussen de ontwerpende partijen (Revit, dalux, briefbuilder..?)*
    c. *Met de eindgebruiker (Revit, dalux, briefbuilder..?)*
    d. *Is dit een gebruikelijke manier?*

Uw antwoord…

8. *Hoe ervaart u de validatie en verificatie van het ontwerp?*

Uw antwoord…

9. *Hoe wordt er tijdens het ontwerpproces rekening gehouden met het toekomstige gebruik/beheer van het gebouw (in het BIM model)?*
    a. *Is dit een gebruikelijke manier?*

Uw antwoord…

10. *Hoe ervaart u de samenwerking in het project?*

Uw antwoord…

11. *Hoe wordt het proces gemanaged? En hoe ervaart u dit?*

Uw antwoord…

12. *Zijn de BIM managers in dienst of ingehuurd?*

Uw antwoord…

13. *Had u nog toevoegingen of zijn er nog dingen die u anders zou willen zien gaan aangaande voorgaande vragen?*

Uw antwoord…

1b) Vragen met betrekking tot eindgebruikers

1. *Welke eindgebruikers zijn bij het project betrokken: e.g. ziekenhuisbestuur, management, maatschappen, personeel?*

Uw antwoord…

2. *Hoe zijn eindgebruikers in het project betrokken?*

Uw antwoord…

3. *(Hoe) zijn ze in BIM betrokken? -> is dit gebruikelijk/gebeurt dit vaker bij andere projecten?*

Uw antwoord…

4. *Was het een vereiste om in BIM te gaan werken, zo ja vanuit welke partij? Bijvoorbeeld de opdrachtgever/ziekenhuis?*
    a. *Zo ja: Waarom vonden ze dat belangrijk?*

Uw antwoord…

5. *Wat willen ze met het BIM model: is het voor het ontwerp of ook voor het beheer?*

Uw antwoord…

6. *Denken de eindgebruikers dat ze voldoende betrokken worden bij het ontwerpproces?*

Uw antwoord…

7. *Wat zijn hun verwachtingen van het ontwerp en het BIM model?*

Uw antwoord…

8. *Zijn er dingen die ze anders willen zien dan ze nu gaan?*

Uw antwoord…

9. *Had u nog toevoegingen aangaande bovenstaande vragen?*

Uw antwoord…

B.2. English version of the interview

This interview consists of an introduction, relevance, aim of the research, main research questions, sub-questions and interview questions.

Introduction to the research

The subject of this research is **validation and verification of the design of hospital buildings, between the design team and the client/end user, while they work with BIM (Building Information Modelling)**. *Hospital buildings* are *complex building projects,* technically and in terms of the amount of stakeholders involved: which are stated (in literature and interviews) as good projects to work with BIM. *BIM or Building information modelling* are 3D programmes and other digital tools for visualisation and information management, to design, maintain and operate buildings, in which the different project stakeholders can work together.
Validation means that the design or BIM model meets/approves the future functional requirements during the use of the building, *verification* means that the design is correct and the BIM is correctly implemented.

The ***relevance of this research*** lies in the fact that it is stressed in literature and interviews priory held, that the communication with BIM is still a critical aspect in complex projects such as hospitals. Multiple interviewees stated that BIM does not work in practice as is proposed from literature and BIM programme makers. First, there is often a lack of well-functioning communication between actors working with BIM, second, involved actors do not always have the required BIM related skills, and the third, the connection between the design phase and the use of these complex buildings is mentioned as critical by practitioners: in terms of including the use requirements in the design phase in BIM, and the use or readiness of the BIM model for the use phase.

Therefore ***The aim of the research*** is to get a better insight in - and if possible to improve – the processes of communication and collaboration between stakeholders, in the design phase, while they are working with BIM. More specifically insight into validation and verification of the design for the use phase, between different project stakeholders. Further, it is examined how the use/maintenance of the building is taken into account in the BIM model of the design phase.

The Main research question is: In what way is the **functionality of the building** for the **use (phase)** validated during the **design phase** between the **various stakeholders,** while they make use of **BIM**, and how is the information for **use&maintenance of the building** incorporated in the BIM model during the design?

The corresponding **sub questions** are: (full questionnaire hereafter)

1) *To what extent, and in which way is BIM used in the design phase of this hospital as a mean to share information about the hospital between the design team and the client/end-users of the hospital?*

Your answer…

2) *How is the design and BIM model validated and verified between the project team and the client/end-user, and how is BIM used in this process?*

Your answer…

3) *To which extent is there a well-functioning communication/information sharing between the actors within BIM (e.g. due to their competences) and a well-functioning BIM model (e.g. compatibility and interoperability)?*

Your answer…

4) *In which way does the use of BIM influence the collaboration and work process (positive/ negative)?*

Your answer…

5) To what extent is the BIM ready for use by the client during the operation phase (functional process), and maintenance. (Prospective question.)

Your answer…

Interview questions:

This interview includes questions about the design team and about the involvement of end users.

1a) Questions for actors of the design team

1. *What is your role/contribution in the project? For how long have the project team members worked together and did they work together before?*

Your answer…

2. *What kind of contract has the project?*

Your answer…

3. *How are you involved in working with BIM in the project?*
    a. *What is your definition of BIM?*
    b. *How do you use BIM in the project?*
    c. *How do you communicate with BIM?*

Your answer…

4. *Do all project partners make use of BIM?*
    a. *How are your and the other team members skills/competences in BIM?*
    b. *Did you/they work with BIM before?*

Your answer…

5. *Is the BIM a central model or separated parts?*

Your answer…

6. *Does the BIM have added value for the collaboration?*
7. *Does the BIM have added value for the work process?*

Your answer…

8. *How is the functionality of the design validated and verified with BIM (see introduction for description) between the different project partners?*
    a. *Internal (Revit, dalux, briefbuilder..?)*
    b. *Between the designing parties (Revit, dalux, briefbuilder..?)*
    c. *With the end user (Revit, dalux, briefbuilder..?)*

Your answer…

9. *How do you experience the validation and verification of the design?*

Your answer…

10. *Hoe is the future use and maintenance of the building incorporated during the design (in the BIM model)?*

Your answer…

11. *How do you experience the collaboration in the project?*

Your answer…

12. *How is the process managed, and what is your experience about it?*

Your answer…

13. *Are the BIM managers intern colleagues or hired specifically for the project?*

Your answer…

14. *Are there things you would like to add or see differently considering previous questions?*

Your answer…

1b) Questions considering end users

1. *Which end users are involved in the project: e.g. hospital management, staff, partnerships?*
2. *And: How are they involved in the project?*

Your answer…

3. *How are they involved in BIM? (Dalux, Revit..?)*

Your answer…

4. *Was it a request to start working with BIM, and if so from which party? E.g. from the client/hospital.*
    a. *If so: why did they think it was important?'*

Your answer…

5. *What do they want from the BIM model: is it just for the design or also for maintenance?*

Your answer…

6. *Do the client/end users think they are involved enough in the design process?*

Your answer…

7. *What are their expectations of the design and the BIM model?*

Your answer…

8. *Are there things that they would like to see differently than the way it goes now?*

Your answer…

9. *Are there any additions you would like to make considering previous questions?*

Your answer…

Appendix C – Structured table with conclusions and quotes

Subject and conclusions	Quotes Dutch Case	Quotes foreign case
0 - BIM Definition and possible benefits	Dutch case	Foreign case
Dutch case: **0.1.1.** The project manager sees BIM merely as an information model, of which 3D can be a part: the model can also consist of plain drawings.0.1.1. **0.1.2.** The BIM manager sees BIM merely as an information model.0.1.2. **0.1.3.** The Central information manager sees changing roles and possible benefits of time and costs savings, and measuring progression. **Foreign case** **0.2.1** The BIM manager sees BIM as a way of collaborating, to deliver a "clash free" project. **0.2.2.** The project manager sees BIM as a sum of using different programs, for information management, 2D or 3D.	**0.1.1.** *"Het is vooral, hoe hier mee gewerkt is, we hebben eigenlijk vooral het bouwmodel gebruikt, dus het 3D tekenen, en de informatie component zit dan vooral in: wat moet ik uitvoeren. En wij zijn nu vooral bezig om te kijken of we de informatiecomponent voor overdracht naar ons beheer en onderhoud, gekoppeld kunnen krijgen. En nu is het volgens mij separaat, dus het zit niet aan elkaar vast. Het kan heel breed het kan ook heel smal. Je zou BIM ook nog kunnen zien als platte tekeningen. Voor mij is het een bouw informatie model, het is maar net hoe je het.. 3D is daar een onderdeel van, dus het is voor mij niet specifiek dat."* (Project manager, 2018) **0.1.2.** *"BIM is, de modellen die er nu zijn, nu focus je heel erg op 3D en op coördinatie met partijën, maar gaat het natuurlijk vooral ook om de informatie die er in zit. En, met bepaalde informatie die in een model zit in een bepaalde fase, die zal je wel moeten gebruiken om kennis op te bouwen, om ook te zorgen dat je uiteindelijk de kwaliteit krijgt die je wilt, en om dat ook als communicatiemiddel te gebruiken. Om een voorbeeld te geven, het liefst zou je willen dat bepaalde ruimtes worden gedefiniëerd, die krijgen een bepaalde afmeting mee. Op dat moment ga je zeggen, wat zijn nou de eisen, begin je niet zozeer met een 3D model, maar vooral welke informatie moet er aan een ruimte toegevoegd worden. Bij wijze van spreken, hoeveel stopcontacten wil je als eindgebruiker hebben. Dan zit er een bepaalde kennis opbouw*	**0.2.1** *"Ja, er wordt altijd gezegd BIMmen, maar voor mij is BIM gewoon samenwerken, en samenwerking op basis van vooraf gemaakte afspraken, waaraan je moet voldoen zeg maar, om een project clashvrij op te leveren."* (BIM coordinator Architecture, Dutch actor, Foreign case, 30-04-2018) **0.2.2** *"BIM, dat is voor mij ook, als er gebruik gemaakt wordt van twee of meer programma's, waarbij in de, slechts de som van alle programma's het samenhangend totaalbeeld geeft, vind ik ook BIM. Dus Autocad en bijvoorbeeld Word, samen, vind ik BIM, en ik vind ook Autocad, Word en Excel, of wat dan ook, vind ik ook BIM. Omdat er informatie vanuit verschillende kanten samengebracht wordt, heb je slechts door het lezen van de gezamelijkheid, een samenhangend beeld geeft [sic]. Dus het gaat gewoon over de precieze definitie, die je er aan geeft."*[1] (Project manager, Dutch actor, Foreign case, personal communication, May 8, 2018)

	in, en dat is wel het liefste wat je ziet. Maar op dit moment is daar nog veel ruimte voor verbetering zeg maar" (BIM manager, 2018) **0.1.3.** *"En wat je vaak, hoe we het nu zien, is niet dat je dus een BIM coördinator of BIM regisseur aanstellen, maar de projectleider wordt ook verantwoordelijk voor het BIMmen. Je kunt je natuurlijk op inhoud laten adviseren door BIM experts, maar het is onderdeel van het ontwerp overleg. En als je goed BIMt, komen daar allemaal gegevens uit naar voren, waarmee je weer tijd, geld, kosten, inzicht, voortgang zou kunnen meten"* (Central information manager, 2017)	
RQ1 - Use of BIM	Dutch case	Foreign case
Reasons and Motives Dutch and Foreign case: **1.2.1, 1.1.1.** For use and maintenance **Dutch case:** **1.1.2.** for efficiency Foreign case **1.1.6.** For planning and calculation. **Foreign case:** **1.2.2, 1.2.3.** for clash detection and for cost calculation	**1.1.1** *"Het is vooral, hoe hier mee gewerkt is, we hebben eigenlijk vooral het bouwmodel gebruikt, dus het 3D tekenen, en de informatie component zit dan vooral in: wat moet ik uitvoeren. En wij zijn nu vooral bezig om te kijken of we de informatiecomponent voor overdracht naar ons beheer en onderhoud, gekoppeld kunnen krijgen. En nu is het volgens mij separaat, dus het zit niet aan elkaar vast."* 1.1.1. (Project manager, Client, Dutch case **1.1.2** *"dat gaat echt om communicatie volgens mij. En dat blijft dan versnipperd, verspreid, in plaats van één centraal model, waar je met zijn allen naar hetzelfde kijkt.. en ik heb de indruk dat communicatie veel meer tijd kost doordat ze met verschillende systemen werken, ze en we, en ik denk, maar goed ik modelleer zelf niet, dat je als je met zijn allen naar een BIM model kijkt, en daar via BCF communiceert, en op die manier leert samenwerken, dat je misschien wel efficiënter bent. Of dat ook voor de ontwerpfase geldt weet ik niet […] Wel bij de engineering. Dus als*	**1.2.1** *"Een van de voornaamste reden [sic] voor de klant bij het kiezen voor bim is het gebruik van de info in latere fase voor beheer en FM."* 1.2.1 *(BIM manager* (BIM manager Foreign hospital case, Foreign party 1) **1.2.2** *"Dat wordt een soort kick off meeting, waar ook afspraken worden gemaakt hoe we omgaan met clash detectie."* 1.2.2. (Project director, Dutch actor, Foreign hospital case, Januari 11, 2018) **1.2.3** *"Men wil hier in [plaats ziekenhuis] vooral een BIM model om de bill of quantities uit te halen."* (Project director, Dutch actor, Foreign hospital case, Januari 11, 2018) 1.2.3. *"de basisopzet is voor het model om de hoeveelheden er uit te halen. […] vanuit [land] hebben zij coderingen*

	ze echt gaan ontwerpen, dan zie ik wel mogelijkheiden." 1.1.2 **1.1.6.** *"Daarnaast gebruiken wij de modellen ook om te calculeren en te plannen."* (BIM director, main contractor, Dutch case, personal communication, June 1, 2018)	*aangegeven, dus echt alles wat in het model zit, moet de juiste codering hebben […] Dus dat is de conclusie van BIM, dat uiteindelijk kosten management gewoon met ons model kan bepalen wat de prijzen en wat de elementen zijn die er in zitten. Dus dat vraagt ook wel een nauwkeurigheid. En daar moet je ook naar modelleren, je kan ook wel met clash detectie een beetje rekening houden, van als iets door het beton gaat, en je hebt een bepaalde marge, dat het dan, dat ze het dan aan moeten passen. Je moet ook gewoon wel netjes modelleren. En uiteindelijk worden dan ook die sheets er uit gehaald, maar dat is dan een klein beetje een bijzaak, het is, voornamelijk is het de telling van hoeveelheden belangrijk.* 1.2.3 (BIM modeler, personal communication, May 16, 2018)
RQ1 - Use of BIM	**Dutch case**	**Foreign case**
What and how **Dutch case:** **1.1.3.** Working in two models (architecture and installations) in a shared platform. **1.1.4.** High 3D ambitions, back to 2D check by client. **1.1.5.** Clash control by the designing parties in 3D. **1.1.6** To calculate and plan. **Foreign case:**	**1.1.3.** *"Wij hebben alles via Chapoo uitgewisseld, dat is een platform waar we de boel op kunnen zetten, zeg maar. En zo werden ook de BIM modellen uitgewisseld. Die werden op Chapoo geplaatst. Verschillende modellen, geen gecombineerd model. Dus we hebben een installatiemodel, we hebben een bouwkundig model."* 1.1.3. (Project manager, Client, Dutch case, personal communication, April 10, 2018) **1.1.4.** *"Bij de uitvraag, BIM protocol hebben we doorgezet naar de aannemers. En we hebben zeker in*	**1.2.4** *"Voor dit project werd BIM ingezet van de fase 'detailed design'. Het concept werd in 2D geschetst in autocad en sketchup. Het voorontwerp werd wel als model in Revit opgemaakt, maar er werd pas een BIM proces gestart vanaf de fase 'detailed design'. Er werd echter nog vaak in 2D/dwg info uitgewisseld daar niet alle partijen overtuigd zijn van het BIM principe"* 4 (BIM

1.. BIM in detailed design phase **1.1.7.** Installations with Dynamo, Revit and Excel **1.1.8.** Architecture with Revit and Navisworks Later, Dalux was added, to review tasks and issues.	*het begin geprobeerd daaraan vast te houden. Alleen dat bleek al vrij snel niet werkbaar te zijn. Toen zijn we er eigenlijk van af gestapt, en hebben we eigenlijk het BIM proces, of 3D tekenen beter gezegd los gelaten, en zijn we de gebouwen gewoon gaan aansturen op basis van 2D tekeningen." Die 2D tekeningen zijn wel weer afgeleid uit de 3D modellen. Maar de structuur zoals gemaild, dus de algemene projectspecificatie, die vergadercyclus van twee weken, die heeft eigenlijk niet of nauwelijks plaats gevonden. Wat wel heeft plaatsgevonden, het heeft wel plaats gevonden, alleen meer onderling tussen installateur en bouwkundige aannemer, bouwkundige aannemer" […] We hadden eigenlijk gewoon voortgang verwacht, en die vergadering was eigenlijk in mijn optiek, we waren meer in discussie wat moeten we nou wel wat moeten we nou niet, en de kwaliteit van het aangeleverde DO model was niet genoeg voor ons om door te pakken […] Dus ik heb niet het contract losgelaten, maar we het BIM proces zoals die hier staat, heb ik losgelaten, in overleg met [Ziekenhuis], dat dat dus, dat speelt een rol. Dat het [ziekenhuis] dus niet geschikt was, ingericht was op het controleren van 3D modellen. Die wilde platte tekeningen zien. En op de bouw wilden ze ook platte tekeningen, op een gegeven moment denk ik van ja, nouja, dan ben ik aan het duwen en trekken om het allemaal in BIM te krijgen, maar er is gewoon, het is door het totale team eigenlijk niet gedragen. Toen ben ik omgeschakeld. Toen heb ik gezegd van, we laten het los, maar ik wil wel dat jullie de platte tekeningen genereren uit 3D modellen, zodat ik wel aan het einde van het project een opgeleverd 3D model krijg, zoals in het protocol is*	manager, Foreign party 1, Foreign case, personal communication, May 8, 2018) **1.2.5** *Voor de installaties deel [sic] […] Op dit moment gebeurt, vullen de ontwerpers iets in in excel, en wij lezen dat in in het model, dat doen we met een aantal programma's. We gebruiken nog niet echt een data base voor […] Ja meestal we werken in een combinatie van excel, dynamo en Revit."* (BIM coördinator MEP, Dutch actor, Foreign case, personal communication, May 7, 2018) **1.2.6.** *"wij werken dus het bouwkundige model uit. En wij hebben daar aan gelinkt het constructieve model, en het casco model, het casco model is zeg maar de gevel. Wij gebruiken daarvoor Revit, en daarmee werken we dus in principe alles uit voor zeg maar de telstaten, daar genereren we ook de tekeningen uit.. Verder wordt er nog gebruik gemaakt van Autocad, om de meubeltjes op orde te krijgen, daar ben ik verder niet zo bij betrokken. En voor het clashen van de modellen moeten wij Navisworks gebruiken, dat is ook software van Autodesk. En we werken samen zeg maar door middel van een Revit server, ben je daar bekend mee? […] Nou een Revit server, dat is gewoon een centrale plek, waar het model staat, daardoor kun je*

	vastgesteld." 1.1.4. (Project manager, Client, Dutch case, personal communication, April 10, 2018) **1.1.5.** *"ik weet ook wel dat [Hoofdaannemer] en [Adviseur E&W] diverse keren modellen hebben uitgewisseld, maar in de tijd dat dat gebeurd is, dat zou je eigenlijk [hoofdaannemer] zelf moeten vragen, of [adviseur E&W]. Ja, in die controle rondes zeg maar, clash controle rondes was ik niet, of [ziekenhuis] eigenlijk niet meer aangehaakt, want, ja.. niet zo boeiend eigenlijk meer."* 1.1.5. (Project manager, Client, Dutch case, personal communication, April 10, 2018) **1.1.6.** *"Ik kijk af en toe in een model om bepaalde knooppunten te onderzoeken. Je merkt dat onderaannemers nog gewoon van tekening werken. De timmerlieden buiten trouwens ook. Vandaar dat ik het ook van 2D tekenwerk voorbereidt."* (Work planner, main contractor, Dutch case, personal communication, June 11, 2018)	*met meerdere mensen aan één model werken, ook vanaf verschillende locaties."* (BIM coördinator Architecture, Dutch actor, Foreign case, personal communication, May 8, 2018) **1.2.7.** *"nu is de opzet op zich, dat we nog twee modellen hebben, één is bouwkundig model waarin alle informatie in zit, en we hebben een los model van een sheet model, die eigenlijk puur is om de informatie, de 2D informatie in beeld te brengen. En vaak als de modellen heel zwaar zullen gaan worden, dan kan het ook nog zijn dat we de modellen nog verder gaan opsplitsen, maar het is wel handig om zo veel mogelijk informatie in één model te hebben, ja als er dingen wijzigen, en dan moet je alle modellen door om het weer aan te passen, families opnieuw in te laden.* (BIM modeler architecture, Dutch actor, Foreign case, personal communication, may 16, 2018) **1.2.8.** *Tot deze week werd het ontwerp altijd op de klassiek manier gevalideerd, op basis van 2D tekeningen, echter wel met het model erbij voor meer inzicht. Vanaf deze week werd het Dalux platform actief (Dalux field) en wordt het finale ontwerp gevalideerd via Dalux tasks en issues." 1.2.8.* (BIM

		manager, Foreign party 1, Foreign, case, personal communication, may 8, 2018)
RQ2- wellfunctioning communication and BIM model	Dutch case	Foreign case
Dutch case: **2.1.1.** Collaboration is critical for a successful project. **2.1.2.** Benefits of 3D to involve end-users **2.1.3.** And virtual reality **2.1.4.** In this particular project not yet a central role as communication tool **Foreign case:** **2.2.1,** Importance of good communication, **2.2.2** regardless of BIM or no BIM, negative, **2.2.3.** or positive impact **2.2.4.** Not everyone knew the program Dalux **2.2.5.** so a pilot was organized. **2.2.6** Importance of meeting face to face	**2.1.1.** *Het BIM uitvoeringsplan van [main contractor] sluit aan op de uitvraag (BIM protocol) van het [ziekenhuis]. Vervolgens is het aan [main contractor] om te zorgen dat de leveranciers zicht [sic] aan het BIM uitvoeringsplan van de realisatie fase houden dat binnen de scope valt. Zodra er een hiaat in de informatie van het BIM protocol kan een leverancier onmogelijk goed invullen.* (BIM director, main contractor, Dutch case, personal communication, June 6, 2018) **2.1.2.** *"Ja, zeker wel. Ik denk dat meer mensen een plaatje begrijpen waar een ruimte wordt getekend met gegevens, of tenminste gewoon 3D, met hier is het raam en daar is de deur en dat zit zo weer in elkaar, dan dat ze van tekeningen kunnen lezen. En technici zullen dat nog wel goed kunnen want die zijn er voor opgeleid hoe je tekeningen leest, maar juist gebruikers zien veel liever een combinatie. […] in het ziekenhuis heb je dan mensen die inderdaad gewoon nooit met de bouw bezig zijn"* (Central information manager, Client, Dutch case, personal communication, November 10, 2017) **2.1.3.** *"virtual reality wel, dat je echt door een model heen loopt, of afbeeldingen van het model kan koppelen aan de plek waar je staat in de werkelijkheid, dat zien we wel. Dus ja, op die manier werken we daar wel naar toe, maar het is niet een standaard onderdeel van het ontwerpproces. […] Ook om gebruikers te laten zien, dat is één van je laatste vragen hoe we daar mee om gaan, ja dat helpt, absoluut. We hebben een bezoek aan de*	**2.2.1** *"Zoals wij dat deden, wij organiseerden, dus wij werkten allemaal onafhankelijk in een model. Elke vrijdag middag zorgden wij er voor dat alles ge-upload werd, en dan hoe groot clashes ook waren, dan stond alles in één model. Dan hadden wij op dinsdag, hadden wij clashes detectie overleg. Nou dan hadden wij een BEP, een BIM execution plan, en daarin stond wat wij als clash beschouwden. En dan zaten we met partijen aan tafel, en die partijen bekeken dan, dan was er een voorzitter, de voorzitter van het clash detectie overleg. En die zei, nouja, ik zie deze clash, mensen daar moeten we iets mee. En dan werd er een actie aan gekoppeld, want iemand moest dan plaats maken, of een kanaal moest omgelegd worden, anders ontworpen, of er moest een wand weggehaald worden, of iets dergelijks, dus dat is, nouja, die vorm van communicatie moet dan wel op gang komen. Want anders dan doet iedereen ongelooflijk zijn best, maar dan heb je dat het model, nouja, het is eigenlijk het samenwerken in een keten, die moet leiden tot één eindproduct. Als het in die keten niet goed gaat, dan is het eindproduct ook niet*

	bouwplaats gebracht een paar weken terug, met mensen die daar daadwerkelijk komen te werken, en die staan dan in een ruimte met afgetimmerde plankjes en dingetjes, en van hier komt dan straks een muurtje, en dan staan ze daar en dan staat dat muurtje daar in 3D, ja en dan snap je wel hoe het in elkaar zit. Maar dat is gebruikt, of gebruikt.. om ze een beetje leuk inzicht te geven. Het is niet gebruikt in de ontwerpfase om ze een besluit te laten nemen. […] En dat is wat je eigenlijk wilt, dat ze de keuze maken deur kan links deur kan rechts, of we kunnen deze ruimte hier en die daar doen, dat soort berekeningen over loopafstanden of inzicht of handigheidjes, dat, zover zijn we nog lang niet. […]Terwijl je wel denkt, ik denk dat daar behoefte aan is. Je kan dan nog omgaan met meer complexere uitgangspunten omdat het visueel wordt. En als je het allemaal in BIM doet ook meetbaar." (Central information manager, Client, Dutch case, personal communication, November 10, 2017) **2.1.4.** *"als opdrachtgever wil je er heel veel voordeel uit halen, je merkt dat bij de uitvoerende partijen er nog wel wat terughoudendheid is, die willen er niet té veel energie in steken. Want die ervaren dat ook, tijdsdruk, we krijgen het niet op tijd af, dus, het kost altijd een beetje moeite, je merkt echt nog dat het de overgangsfase is. Het wordt wel steeds makkelijker om met behulp van modellen etcetera te communiceren, om bepaalde problemen aan te geven met behulp van modellen. Niet alleen maar meer PDF'jes naar ons sturen, maar eigenlijk hoe groter een project, hoe eerder mensen terug grijpen op wat ze kennen. Dus dat betekent PDF'jes met opmerkingen, veel meer*	*goed."*[2.2.1] (Project manager, Dutch actor, Foreign case, personal communication, May 8, 2018) **2.2.2.** *"Als jij bedoelt, het gebruik van BIM en Revit, dan zeg ik dat dat niet anders is dan tien jaar geleden. Communicatie is alles bepalend. Dus als ik tien jaar geleden niet goed communiceerde ging het is, en zo is het nu ook. Ik denk zelfs dat het nu gecompliceerder is geworden, omdat we in een tijd zitten, waarin dit nog geen alledaagse praktijk is."*[2.2.2] (Project manager, Dutch actor, Foreign case, personal communication, May 8, 2018) **2.2.3***"klanten verwachten 2D tekeningen, meestal. Of ze vinden dat makkelijker. Maar we maken toch een model omdat, kan veel mee [sic], veel meer er mee, zoals tellen van alle lengtes van leidingen en kabels enzo. En het coördineren van problemen. [...] Ja ik heb vroeger vaak gewerkt met veel, alleen 2D. En het is zo veel makkelijker om problemen op te lossen, in het 3D model."2.2.3 (BIM coordinator MEP, Dutch actor, Foreign case, personal communication, May 7, 2018)* (BIM coordinator MEP, Dutch actor, Foreign case, personal communication, May 7, 2018) **2.2.4** *"Dalux is.. Nee ik nog niet, en Joseph heeft het wel*

	mailtjes sturen, dus het is nog niet zo dat BIM echt een centrale rol heeft in het project, als communicatiemiddel zeg maar[…] Hoewel je dat eigenlijk wel zou willen he, er is hier wel een bepaalde visie van waar het naartoe moet gaan. Kijk, BIM is, de modellen die er nu zijn, nu focus je heel erg op 3D en op coördinatie met partijën, maar gaat het natuurlijk vooral ook om de informatie die er in zit. En, met bepaalde informatie die in een model zit in een bepaalde fase, die zal je wel moeten gebruiken om kennis op te bouwen, om ook te zorgen dat je uiteindelijk de kwaliteit krijgt die je wilt, en om dat ook als communicatiemiddel te gebruiken. Om een voorbeeld te geven, het liefst zou je willen dat bepaalde ruimtes worden gedefiniëerd, die krijgen een bepaalde afmeting mee. Op dat moment ga je zeggen, wat zijn nou de eisen, begin je niet zozeer met een 3D model, maar vooral welke informatie moet er aan een ruimte toegevoegd worden. Bij wijze van spreken, hoeveel stopcontacten wil je als eindgebruiker hebben. Dan zit er een bepaalde kennis opbouw in, en dat is wel het liefste wat je ziet. Maar op dit moment is daar nog veel ruimte voor verbetering zeg maar. (BIM manager, Client, Dutch case, personal communication, april 10, 2018)	*eens gezien. Een andere BIM coördinator van MEP. Ik heb nou vorige week die cursus gezien, en op zich is het niet hogere wiskunde. Het is gewoon een kwestie van de juiste parameters toevoegen aan hetgeen wat je wil uploaden naar de Dalux omgeving, en vanuit daar kun je het model bekijken, en reviewen, kun je opmerkingen plaatsen. Dan kun je ook replyen op de opmerkingen die je krijgt, of je moet verwerken in het model."* (BIM coordinator Architecture, Dutch actor, Foreign case, personal communication, April 30, 2018) **2.2.5** *"Wij hebben al een test gedaan, dat gaat goed. Maar ik ben benieuwd wat die klant er van vind, dat, als klant kan goed mee werken [sic], dan hoeven wij ook minder 2D tekeningen te maken, die helpt ons, we moeten alleen zorgen dat het model is goed. […] Ja, het ziet mooi uit, het draait heel snel, in vergelijking met Revit ofzo, dit is veel handiger. En wat je kan ook doen is, 2D tekeningen er in laden, om die model, dus je kan 2D tekeningen bekijken, en ook zien hoe dat zit in 3D. Het is heel intuitief, en je hebt veel meer informatie, dan. […] alle verschillende disciplines hebben een model ingeladen, en ook een paar plattegronden eromheen, en we hebben ook getest hoe je kan opmerkingen plaatsen,*

		op die tekeningen in het model. En iedereen krijgt dat te zien, of ze krijgen een melding dat iets is gebeurd. En dan, je kan ook een antwoord terugsturen, op een opmerking, en dan krijg je een hele lijst van wat is besproken, en hoe het is opgelost. Dat is heel goed om.. […] het te beheren, en kijken wat is af en wat niet. […] Dus het idee is dat eerst [foreign party 1] en dan de klant, plaatst een opmerking in het model. En dan wij zorgen dat dat goed verwerkt en beantwoord..” (BIM coordinator MEP, Dutch actor, Foreign case, personal communication, May 8, 2018) **2.2.6** *“Nou, intern, wat ik net al zei, intern MEP en architectuur is nog een beetje twee losse onderdelen. Ja en, de communicatie met [foreign party 1] loopt ook wel wat stroefjes, dat heeft ook wel te maken met de manier van bouwen, het is [buitenland], en dan heb je ook nog een [anderstalige] opdrachtgever, dus die communicatie maakt het ook wel moeilijk, Engels is het ook nog wel eens dat je door elkaar heen praat. Ik moet wel zeggen nu we twee keer op locatie zijn geweest, dat dat wel wat oplevert. Ook gewoon nu, in het verdere mail verkeer is het niet meer zo’n afstand, als je snapt wat ik bedoel he, je mailt sneller even van hé, eh, hoe zit dit, je weet een beetje meer van wie je moet hebben.. en ook hoe je met elkaar om kan gaan zeg maar. En intern zeg*

		maar, als je kijkt naar gewoon het architectuur deel, dan is de communicatie gewoon goed. Ik bedoel, we zijn allemaal bereikbaar, we kunnen met elkaar mee kijken, we hoeven niet persé op locatie te zitten, we kunnen mee kijken via skype, bellen, overleggen. 21;39 Maar toch is het ook wel prettig om hier een of twee dagen te zijn." (BIM coordinator Architecture, Dutch actor, Foreign case, personal communication, April 30, 2018)
RQ3 – Validation and verification	Dutch case	Foreign case
General: **3.2.1** – Often done by means of user consultation **Dutch case:** **1.1.5.** Clash control by designing parties **3.1.1.** Only the end user can validate. **3.1.2.** Validation requirements: law and internal requirements **3.1.3.** Validation of the BIM models by the project manager, **3.1.4.** As well as by the BIM manager during the process **3.1.5.** Internal validation of the design by the project manager **3.1.6.** Validation internally by the end users **3.1.7.** Explanation of reviewing matrix which is used for validation and verification **Foreign case:** **3.2.2.** Sporadical	**3.1.1.** *"Er is altijd maar 1 partij die kan valideren en dat is de eindgebruiker. Het enige wat ik zo snel kan bedenken om een ontwerp te valideren is door middel van VR, maar hoe representatief is dit in vergelijking tot de werkelijkheid.. Het valideren komen wij in de praktijk niet tegen.* *Het verifiëren van de hoort bij onze dagelijkse werkzaamheden. Hiervoor is geen aparte tool gebruikt."* (BIM director, main contractor, Dutch case, personal communication, June 6, 2018) **3.1.2.** *"Ja deels wat je al aangaf van wetgeving. Deels ook beleid van [ziekenhuis] hetzij op het gebruik, dus schoonmaak, wat voor eisen dat zijn, reinheids eisen, dat soort specificaties, unit infectie preventie en veiligheidstemming […] Andere is bestaande installaties, dus dat we mensen vanuit vastgoedbeheer aangeven dat iets aan moet sluiten op een bestaande infrastructuur.* *Dus dan is het een eis dat het daar ook op aansluit, of het is er al, en dat kan gaan tot aan het niveau van de leverancier, dat je een bepaald apparaat, de brandmeldinstallaties,*	**3.2.1** *"In ziekenhuisland […] omdat dat enorme cultuur is van gebruikersoverleg enzovoort, eigenlijk vindt die requirements on the way plaats, nog meer."* (Project director, Dutch actor, Foreign case, personal communication, January 11, 2018) **3.2.2.** *"Die eindgebruiker kennen we eigenlijk niet zo goed. Die zit op de, wij werken als subcontractor van [architectenbureau] he. En die doen de gebruikersoverleggen, en heeft gesprekken met de eindklant zeg maar. Daar zitten wij nooit bij, wij hebben wel wat verslagen maar dat is allemaal in [taal] dus die lezen we moeizaam en slecht, of niet. Dus we draaien heel erg op input van die wij van [architectenbureau] krijgen"* (Project director, Dutch actor, Foreign case, personal communication, January 11, 2018) **3.2.3.** *"Eigenlijk spreken wij*

communication between hospital and Dutch subcontractor **3.2.3.** Sometimes easier to ask directly to e.g. a doctor **3.2.4.** Validation requirements: more to country specific requirements than to internal requirements **3.2.5.** V&V between design team and client: in Dalux **3.2.6**. Information needs of design team and client are different **3.2.7, 3.2.8, 3.2.9:** Internal clash detection Dutch subcontractor: MEP, Architecture, and between Arch and MEP **3.2.10.** Validation: sent to Foreign party 1, together at location, then back to Dutch subcontractor.	*is een bekend voorbeeld, die moeten aansluiten op de bestaande brandmeldinstallatie, dus dat moet gewoon dezelfde leverancier zijn, op dat niveau. En de andere is het weer, ja, hoe is de informatie verzamelen, delen inrichten, dat kan ook zomaar schelen. Dus dat zijn type eisen die je altijd mee geeft aan je aanbesteding, zodat iemand ook weet wat die moet gaan maken, en aan welke context je iets gaat maken.* (Central information manager, Client, Dutch case, personal communication, April 10, 2018) **3.1.3.** *"ben ik nu aan het controleren, maar dat zijn de modellen die jij ook gezien hebt, van wat is er nu, wat is de kwaliteit daarvan, en kunnen wij die kwaliteit goed gebruiken in ons onderhouds, he en beheer."* (Project manager, Client, Dutch case, personal communication, April 10, 2018) **3.1.4.** *"dan moet er iets van de kwaliteit gevonden worden, om te zorgen dat de modellen die bij de adviseurs vandaan komen richting de uitvoerende partijen wel goed genoeg zijn om mee verder te gaan, dus dat betekent dat er eigenlijk van twee kanten aan getrokken en geduwd wordt, want aan de ene kant vragen wij een bepaalde kwaliteit van de uitvoerende partijen, maar dat betekent dat de modellen van de adviseurs ook goed genoeg moeten zijn, zonder dat wij daar zelf nog een bepaalde vertaalslag of verdieping aan toe moeten voegen, in de zin van detaillering of iets dergelijks, dus dat is eigenlijk goed het gesprek voeren met beide partijen" […] "je zit tussen die partijen in, er wordt van alles gezegd over die BIM modellen, en dan is het ook mijn taak om daar een reactie op te geven, klopt dat ook echt, is die kritiek terecht of niet, kun je ook verwachten dat bepaalde*	*deze mensen nooit. Ja, heel heel af en toe. Nu moet ik een excursie organiseren in Nederland voor deze mensen, en dan kom ik zeker met ze in contact. En dat is wel een deel van, dat is toch wel een uitdaging voor ons. Soms zouden wij heel graag. Soms zouden wij heel graag direct iets aan hen vragen. Dus als je aan een dokter vraagt van waarom wilt u nou dat, bijvoorbeeld dat het altijd 23 graden is, nou dat kun je veel beter met zo iemand direct bespreken dan dat dat eerst van hem naar hem, en dan weer zo gaat. Maar ja, daar kun je je wel iets bij voorstellen denk ik* […] *"Dus eigenlijk is het zo, hiërarchisch, zij (Buitenlandse Architecten) hebben een opdracht aanvaard van hun (Het ziekenhuis), en wij zijn sub-consultant voor hun (Buitenlandse Architecten), en kijk, wij komen alle twee uit Nederland, wij zeggen je en jij tegen elkaar, dat zeg ik in (land) niet. […] En dat is, richting (land) ook sterk, dus ik denk dat vanwege de vlotheid in het spreken van (taal), en zeker ook vanwege de hierarchie, en de verhoudingen die in die daar dus gelden, dat er ooit gezegd is, nou weet je wat, het moet altijd via ons. Nou, dat is wel eens jammer. In Nederland heb ik dit zo nog nooit meegemaakt. Want voordat ik.. ik werk dus nu hier bij deze afdeling, en daarvoor heb ik dus, dat zei ik net al, aan vliegvelden gewerkt, en daarvoor heb ik dit al 12 jaar gedaan. Dit is alles wat mensen verzorgt en*

	informatie in het model zit of niet, en in welke fase dan." (BIM manager, Client, Dutch case, personal communication, April 10, 2018) **3.1.5.** *"platte tekeningen, verstrekt via Chapoo.[…][Ziekenhuis] is dus nog niet ingericht op toets op 3D. We willen het wel gaan doen maar het is nu nog niet zo. […] Als je dat eenmaal, als we daar handig in worden met elkaar, […] dan denk ik wel dat het handig is, omdat je gewoon één medium hebt, dat is gewoon het gene, als het weer een vertaling is van tekeningen, dit is gewoon allemaal, komt uit één ding, dus dat kan niet fout. Dus dat vind ik, dat is zeker beter. Nu zijn in dit project uit het 3D model platte tekeningen gegenereerd, en die zijn gecontroleerd en gevalideerd door de betrokken partijen. En daar hebben we gewoon toetsingsmatrixen voor, waarin iedereen opmerkingen kan maken, en die toetsingsmatrixen, nouja, die heb ik dan in beheer, ik moet zorgen dat alle opmerkingen die gemaakt zijn eigen, óf worden beantwoord doen we niks mee, óf worden verwerkt in het volgende proces."* (Project manager, Client, Dutch case, personal communication, April 10, 2018) **3.1.6.** *"Nou daar hebben wij wel een vrij strak proces voor. Wij vragen eerst, nou er is een behoefte vanuit de organisatie voor een soort gebouw, of voor een soort ruimte. Nou dan moeten we helemaal op deze manier wat we precies gaan doen, wat de eisen zijn aan die ruimte, we hebben zelf een standaard ruimte waarvan we ook weten, dit is een wel beetje onze ervaring, zo moet zo'n ruimte er uit zien, dan gaan we dat met een*	*opsluit. Dus ik heb al ontzettend veel ziekenhuizen en psychiatrische instellingen, forensische psychiatrie gedaan, maar het is mij nog nooit voorgekomen dat ik niet direct met medische staf of de opdrachtgever kon spreken."* (Project manager, Dutch actor, Foreign case, personal communication, March 26, 2018) **3.2.4.** *"Dat daadwerkelijk verifiëren en valideren, ten opzichte van een programma van eisen, en vervolgens een ontwerp wat je maakt, niet zo aan de orde is als in de situatie dat je als ontwerper een programma van eisen krijgt, en dan aan de slag gaat. De verificatie en validatie gaat dus meer in de richting van de eisen, de genormeerde voorschriften, die in [land] van toepassing zijn, dan naar een programma van eisen. Een voorbeeld dat we recent, nouja een verandering die we recent, die heel recent is, wij hebben een, we hebben onze afdeling hematologie, en nou, voor zo'n afdeling gelden in Nederland eisen, dus je moet zo vaak de ruimte inhoud verversen, temperatuur X, vochtigheid Y."* (Projectmanager, Dutch actor, Foreign case, personal communication, March 26, 2018) **3.2.5.** *"Veel,minimum van vier per dienst. Eén of twee afgevaardigden per dienst, een voorbeeld hiervan is de technische dienst. […] De test kamers zijn getest door zo'n 150 personen. Alle eindgebruikers moeten het*

	ontwerpteam verder uitwerken, en op een gegeven moment krijgen ze dan een afspraaktekening noemen we dat, daar staan letterlijk de afspraken op wat ze krijgen, zoveel ruimte, zo groot, zo afgewerkt, met zoveel raampjes en deurtjes, en zoveel stopcontacten. Daar zetten ze hun handtekening op, en dat gaat dan het ontwerp in hoe we dat gaan maken, en dan krijgen ze terugkoppeling als we afwijken. Als we bijvoorbeeld als er één of andere reden is, iets wat we niet op deze manier kunnen maken, dan gaan we weer terug naar de eindgebruikers, die deur moet die daar, of deze ruimte wordt wat kleiner, kun je daar mee werken, of gaat dat niet. Dan keuren we dat weer goed, etcetera etcetera, totdat het er staat. En dan zijn ze een tijdje ook niet geïnformeerd, want dan gaan we het echt bouwen, dan moeten ze er maar op vertrouwen dat we maken wat we hebben afgesproken met ze. En aan het einde van de rit leveren we het weer op aan ze: kijk dit was de afspraken tekening, dit heb je gekregen, dus dat werkt op die manier. En soms hebben we ze halverwege het traject nog nodig om aanvullingen te geven over een apparaat wat zij nu gekocht hebben en wat dan weer invloed kan hebben op het ontwerp. Goed daar komen ze zelf ook wel mee.. van goed ik heb toch iets nieuws gekocht mag dat even mee..” 3.1.5. (Central information manager, Client, Dutch case, Personal communication, November 10, 2017) **3.1.7.** *“Dat is gewoon een excel modelletje, zou je kunnen zeggen, en dat is eigenlijk gewoon een platte opmerkingsmatrix, iedereen kan zeggen wat die wil, wel op rubrieken, en iedereen heeft hierin*	*goedkeuren. […] Niet elke eindgebruiker kan een plan lezen, of weten wat ze er mee moeten. […] We geven dan meer uitleg tijdens vergaderingen […] het is per eindgebruiker afhankelijk wat ze kunnen lezen per schaal, soms denken ze dat de [ruimten] te klein zijn. […] Eindgebruikers zijn verpleegkundige of dokter. […] wij werken niet alles uit in 3D, dit kost teveel tijd en moeite. Tijdens de ontwerpfase hebben we vaak verschillende varianten moeten uitwerken. […] De testkamer is echt gebouwd, in varianten en gematerialiseerd, ramen en muren zijn echt geplaatst”* (Project Architect, foreign party 1, personal communication, April 19, 2018) **3.2.6.** *“Wij gaan communiceren zeg maar, door de modellen up te loaden in een andere viewer zeg maar, Dalux viewer, heb je iets van meegekregen denk ik. Ehm.. straks ga ik het model dus ook daadwerkelijk uploaden, dan gaan we hem testen, dat is dan eigenlijk de pilot. En daarna zal het worden toegepast zodat de opdrachtgever kan mee kijken op tekeningen en in het model. Dus zij kunnen, ja, wij geven eigenlijk opdrachten om het model te controleren, en zij kunnen dus opmerkingen plaatsen, en die zullen wij dan moeten verwerken.”* (Project Architect, foreign party 1, personal communication, April 19, 2018)

	zijn rol, en validatie en toetsing, wordt vantevoren wordt bepaald, we werken volgen Prince2, projectmanagement systeem. En dat wil eigenlijk zeggen dat we vantevoren bepalen wie de stakeholders zijn, en wie wat moet controleren, verantwoordelijk is voor welk onderdeel, dus iedereen kijkt daar naar met een hele beperkte scope. En dat maakt het in een ziekenhuis ingewikkeld, maar dat is waarom communicatie zo vreselijk belangrijk is, dit werd getoetst door, […] we hebben een [afdelinggerelateerde eenheid], dat zijn twee mensen. We hebben BHV, 1, we hebben toegangsbeheer, 2, we hebben routing en logistiek, 1, we hebben twee mensen die gaan voor de facilitaire dienst. We hebben een installatie inspecteur, we hebben een bouwkundige inspecteur, dan heb ik er al 12. Dan heb ik er 3 van de afdeling zelf, dus de afdeling gebruikers, dus de werkende gebruiker, [afdeling], die dan wel door 1 iemand wordt vertegenwoordigd, maar die hebben met zijn 3en getoetst. […] Dat zijn dus eigenlijk de werkelijke gebruikers, dus dat is een gebruikers vertegenwoordiger, een afdelingsmanager en gebruiker.. eh proces manager ofzo. 29:59 En vervolgens hebben we dan ook bij het bouwbureau waar wij, hier zitten ook dus toetsers. Nou, dat is, de architect, de constructeur, de installatie adviseur, nouja, die zitten allemaal er in, nou, opgeteld kom je, nouja, ik denk niet dat ik aan 26 kom, maar 20 zijn het er zeker […] extern is dit niet getoetst, dus als je, mijn rol, verificatie en validatie is, voor mij is het alleen maar intern. Dus eigenlijk." (Project manager, Client, Dutch case, Personal	**3.2.7.** *"Een opdrachtgever krijgt ook veel meer, waarbij die in heel veel gevallen niet weet, wat die er mee moet. Of hij heeft bij zichzelf nog geen proces ontwikkeld, dat ie er iets mee kan. Kortom, je moet veel meer uitleggen, en je moet aan de voorkant veel beter nadenken, wat heeft mijn opdrachtgever nou eigenlijk nodig? En we hebben denk ik, nou, ik schat, 25 of 30 jaar lang, hebben we kunnen wennen aan het gebruik van Autocad, en hoe dat er dan uit zag. Nu moeten we onszelf ook de tijd geven, om dit met laten we zeggen, Revit, en alle data die je daar in kunt stoppen. En het gebruik er van, om dat tot volwassenheid te brengen."* (Project manager, Dutch actor, Foreign case, personal communication, May 8, 2018) **3.2.8.** *Dus wat wij doen is dat wij, dus we controleren eerst intern, en dan sturen we iets op, dan controleren we in [locatie], daar is een afspraak voor gepland, en de opmerkingen die daar uit komen, die verwerken we dan weer in Nederland.* (Project manager, Dutch actor, Foreign case, personal communication, March 26, 2018) **3.2.9.** *"Wij proberen in eerste instantie geen clashes te veroorzaken, dat is het beste. Kost minder tijd om het in één keer goed te doen dan alles oplossen. Dus we zitten heel vaak bij elkaar om werk te plannen, tussen de disciplines. En we hebben één keer in de week project overleg, waar dat soort

	communication, November 10, 2017)	*dingen worden besproken. En daarmee gaan we pas op het eind van het stuk werk een clash detectie doen, om te checken wat, hoe dat gaat."* (BIM coördinator MEP, Dutch actor, Foreign case, personal communication, May 07, 2018) **3.2.10.** *"Nouja, intern, is het de taak van de modelleurs om een clashvrij model te maken, dus wij mogen niet clashen met de constructies, en dan kun je het ook weer.. definities en plakken, dat je zeg van.. heb je dat nog meegekregen in de vorige vergadering, stel dat daar een balk loop, en de wand komt daar tegenaan, en je steekt er een stukje door, dan kun je dus een stukje uitknippen, maar je kunt ook zeggen van: hij loopt er door heen, en dat is een clash die we accepteren, alleen moet je dat vooraf wel goed afspreken."* (BIM coördinator Architecture, Dutch actor, Foreign case, Personal communication, April 30, 2018) **3.2.11.** *"Dus dat is eigenlijk intern […] we gaan ook MEP en het interieur model gaan we clashen, voordat wij dat naar buiten brengen naar [foreign party 1], en dan komt er nog een clash controle zeg maar vanuit de opdrachtgever. En de opdrachtgever van onze opdrachtgever die kijkt natuurlijk ook door het model heen. Die zal er waarschijnlijk toch nog op een andere manier naar kijken, zeg maar, van de bruikbaarheid, of er misschien toch dingen anders moeten, en daar

		wordt Dalux voor ingezet. En ehm, het clashen gaat met Navisworks, dus de interne clash zeg maar, dat doen we met Revit, clash detectie. Dan hebben wij onderlinge clash controles als MEP, bouwkundig, interieur, en dat gaat met Navisworks. Dus wij moeten dat ook aanleveren. En vervolgens gaat [foreign party 1] ook clashen met Navisworks. En de modellen staan straks op Dalux, en dat is dan voor de opdrachtgever van [foreign party 1], onze opdrachtgever. […] En die kunnen opmerkingen geven, ja […] Nee, de opmerkingen gaan naar [foreign party 1], en v [foreign party 1], stuurt ze door, dus wij hebben geen rechtstreeks contact met het ziekenhuis [naam]." 3.2.9. (BIM coördinator Architecture, Dutch actor, Foreign case, Personal communication, April 30, 2018)
RQ 4 – Collaboration and work proces	Dutch case	Foreign case
Both cases: **4.1.1., 4.2.1.** Affected by skill level of participating actors. **Dutch case:** **4.1.2.** Possible benefits of the chaning the work process can be less failure costs. **4.1.3.** The process was more traditional than intended. **4.1.4.** There is only one supplier that used BIM. **4.1.5.** They mainly used 2D drawings. **4.1.6.** The willingness to work in BIM of all actors, and the way the hospital was involved and steered	**4.1.1.** *"Je merkt eigenlijk in een project dat nog niet iedereen die ervaring heeft, aan de ene kant zeg je, wat is dan de ervaring met BIM? Voor sommige mensen is dat, de knoppen kunnen bedienen, een 3D model kunnen openen en daar iets uit kunnen halen, en daar iets aan toe kunnen voegen. Aan de andere kant is het ook zo, het gaat ook om een manier van werken. Niet iedereen heeft er ervaring mee, met een BIM proces. Daarom zie je ook dat er op een aantal vlakken, en in een aantal projecten naast een projectleider die er bijvoorbeeld nog niet zo veel ervaring mee heeft, of naast een ontwerpleider, bij een uitvoerende partij, zouden er altijd nog mensen moeten zitten, die je*	**4.2.1.** *"Ik merk wel, bij een ander project zijn de afspraken bijvoorbeeld niet goed gemaakt, en om dan de juiste hoeveelheden uit het model te halen is dan echt een, nouja, een intensieve klus, dus ja, ik mis nog wel eens bij heel veel modelleurs dat ze standaard, of op een bepaalde manier gaan werken. En die standaarden komen wel steeds meer naar voren zeg maar, vanuit de aannemers, en onderaannemers, en dan gaat het met name om codering van objecten, en hoe je ze een naam geeft, maar je komt nog té vaak*

the process was mentioned as possibly affecting the workprocess. **4.1.7.** Time pressure may influence the work process with BIM as well **Foreign case** **4.2.2.** Making good agreements was experienced as important.	*meteen kan aanspreken, om vragen te stellen zeg maar, als het om BIM gaat. Aan de andere kant is het zo, de manier van werken, als je BIM als een, zie het als een soort flow chart, als je dat op die manier zou zien, is het niet persé anders dan wat je normaal gesproken doet, de bepaalde manier van werken zeg maar. Je gebruikt alleen andere tools, en ja, het resultaat in de zin van een model als communicatiemiddel is anders dan je gewend bent. Maar ik ben eigenlijk van mening dat je er gewoon mee moet starten en iedereen zich aan de afspraken met houden en dan zou het vanzelf goed moeten gaan zeg maar. Of vanzelf.. je steekt er uiteraard moeite in maar dan zou het goed moeten gaan zeg maar. Alleen het probleem is een beetje, je ziet nog heel vaak dat er teruggegrepen wordt op manieren van werken die mensen kennen, dus gewoon op een ouderwetse manier van werken. En dat komt, op het moment dat een planning niet gehaald wordt, er komt werk bij, of ik noem maar wat een adviseur die wil het ontwerp kleiner hebben, dat betekent dat de uitgangspunten van de opdrachtgever duidelijk moeten zijn, op het moment dat dat naar achteren schuift, en dan haal je een deadline niet, dus dan zie je, de planning wordt een probleem, en dan wordt er toch weer teruggegrepen op de oude manier van werken."* (BIM manager, client) (BIM manager, Client, Dutch case, Personal communication, April 10, 2018) **4.1.2.** *We zijn er wel van overtuigd dat uiteindelijk, alles wordt in 3D getekend, en eh, vroeger moest je tekeningen controleren en was de werk organisator of de mensen die*	*dingen tegen die niet, die niet voldoen aan de eisen zeg maar, om het er netjes uit te halen. En binnen [dutch subcontractor] zijn ze nu ook bezig om een centrale bibliotheek te maken, en daar alle standaarden in te stoppen, nu werkt iedereen een beetje voor zich. En dat zijn dingen, die kunnen, die zouden ook gewoon veel beter moeten."* (BIM coördinator Architecture, Dutch actor, Foreign hospital case, Personal communication, April 30, 2018) **4.2.2.** *Ja, op zich moet ik zeggen in het project dat het vrij aardig gaat, ja ik praat dan even voor de modelleurs, [naam] en ik zijn wat ervarener modelleurs, er zitten ook wat minder ervaren modelleurs bij, maar op zich, denken we allemaal conform het zelfde protocolletje, en doet iedereen zijn best inderdaad om het gewoon, naja dat je je aan de codering houdt en alles invult als je een wand doet en secuur werkt, dat is natuurlijk ook heel belangrijk met BIM, dat je, even snel een wandje zetten is er niet bij, je moet echt van alles checken, hoogte checken, welke parameters allemaal zijn ingevuld, of het per department ook klopt. Nou maar ik vind dat dat in dit project, dat het wel goed gaat. […] uiteindelijk, in het protocol is het natuurlijk wel super belangrijk om aan te geven*

	*bij het betrokken waren die moesten zeg maar de platte tekeningen vertalen in hoe zit het nu in het 3D zeg maar, in de werkelijkheid. Dat gaat nu automatisch, en dat heeft wel toegevoegde waarde. Ik denk dat de faalkosten uiteindelijk voor een aannemer of voor ons allen, zeg maar, dan wel omlaag gaan, dat geloof ik wel. Maar we moeten nog wel een paar stappen zetten.*4.1.2. (Project manager, Client, Dutch case, Personal communication, April 10, 2018) **4.1.3**. *"Maar goed, de gemaakte keuzes zijn zodanig dat het eigenlijk niet meer aan de orde is. Het is een nice to have geworden in plaats van een afspraak, omdat met name in de uitvoering, wat ik al zei, om traditioneel zeg het maar, te werken. En dat heeft ook gewerkt, want het project is op tijd af, kennelijk werkt dat goed genoeg. […] En dat was voor dit project gewoon het belangrijkste om het mee te doen. Dus wat we wel doen is modelleren, en ons projectprotocol vereenvoudigen, versimpelen terwijl we ervaringen terughoren.. als je het in het project niet gebruikt het hele BIM, dan heb je ook allemaal sturingsgegevens niet meer nodig, dus hoef je die ook niet aan te leveren."* . (Central information manager, Client, Dutch case, April 10, 2018) **4.1.4.** *In het geval van [deel van het ziekenhuis] is er maar 1 bimmende leverancier. Dit is de installateur en de installateur valt onder de regie van het [ziekenhuis].* *Voor wat betreft de bouwkundige werkzaamheden zijn het onderdelen waarvan er geen leveranciersmodellen nodig zijn. Het ontwerpmodel voor de UO uitwerking is overgenomen door [hoofdaannemer] en omgebouwd conform de parameterlijst van het*	*van oké, bepaalde eisen waar je aan moet voldoen. Maar ook, Je hebt zelf nu een beetje opgezet van hoe gaan we fysiek iets modelleren, hoe teken je de wand, doe je dat alleen van een level niveau, of doe je dat inbouwen in het ruimte gebruik, je kan natuurlijk op heel veel manieren kan je modelleren, dat je ook op naamgeving let, of bepaalde, je ziet op de plattegrond dat dit weer groen is [laat iets zien in model] dat is dan omdat het bijvoorbeeld een MEP element is. En lichtgrijs is dan losse inrichting, en als het doorg.. of zwart is dan is het fixed furniture, […] die opzet hebben we ook zelf een beetje bedacht en ook met [fp1] contact over gehad. Maar goed, dat heb ik ook wel ergens in het doctumentje vastgelegd, zo veel mogelijk. Ja het is natuurlijk wel belangrijk om alles, zeker als je in een groot team werkt, dan probeer je zoveel mogelijk alles te stroomlijnen. Maar goed, ik moet wel zeggen dat als je een beetje in het project zit, dat het ook wel automatisch gaat. […] En je kan altijd wel aangeven, bij twijfel altijd gewoon vragen en communiceren, dat blijft natuurlijk gewoon super belangrijk bij zo'n project, anders kun je snel lang elkaar heen de informatie er in stoppen. Dat is zonde.* (BIM modeler architecture, Dutch actor, Foreign case, personal communication, may 16, 2018) **4.2.3.** *"In dit geval werd het proces negatief beïnvloed*

	*Erasmus MC.? (**BIM director**, main contractor, Dutch case)* (BIM director, main contractor, Dutch case, personal communication, June 6, 2018) **4.1.5.** *In geval van dit werk heb ik daar zelf niet zo veel van gemerkt. Wij hebben voornamelijk de 2D tekeningen gebruikt. Echter denk ik wel dat [Kropman] er wel gemak van heeft gehad.* *Het BIM-model was een contractstuk in de overeenkomst die we met het [ziekenhuis] hebben gesloten voor de verbouwing. Hierdoor hebben we wel soms in het model kunnen kijken wat we moesten doen in geval van twijfel over de uitwerking van details. (Work planner, main contractor, Dutch case)* Ervaart toch samenwerking goed: *Goed, maar ik realiseer me wel dat het ontzettend belangrijk is om vooraf duidelijke afspraken te maken over de verantwoordelijkheden per partij. (**Work planner**, main contractor, Dutch case)* (Work planner, main contractor, Dutch case, personal communication, June 11, 2018) **4.1.6** *"dat ligt ook aan onze eigen betrokkenheid, en hoeveel we daarin moeten sturen.. nee kan ik niet zeggen dat het anders beter was geweest of… Ja, meer betrokkenheid van ons, om het BIM proces te organiseren en meer voordelen van BIM te laten zien, maar als de rest dat niet gebruikt, dan is er ook geen voordeel. Je moet het met zijn allen willen. En als een paar mensen niet willen, of een paar partijen niet, omdat ze onder hoge tijdsdruk staan, om een mooi product te maken, dan kun je van alles.. dus dat is een beetje wat het is eigenlijk. […]*	*door BIM, door het gebrek aan kennis van BIM en 3D modelleren in Revit door sommige partijen. Uit ervaring in vele andere projecten (ziekenhuizen en andere) kan ik zeggen dat de kennis van BIM en 3D modellen heel bepalend is voor het slagen van het project in BIM. Het gebrek aan kennis en de wil om te bimmen zijn heel vaak nefast voor een BIM proces en zorgen al te vaak voor een negatieve ervaring. Wanneer echter alle partijen voldoende kennis en wil tonen is het werken in BIM positief voor alle partijen!"* (BIM manager, Foreign party 1, Foreign case, Personal communicationn, May 8, 2018)

	Maar we kunnen ook niet echt sturen, omdat dan onze eigen organisatie ook zich helemaal bewust moet zijn, en op een BIM manier moet gaan gedragen, en het ook in het contract zo afgesproken met zijn, dus er zijn best wel wat zaken die daar mee samenhangen. […] "Maar BIM is een middel, en geen doel. En als dit middel nu niet werkte, dan moeten we kijken waarom dit nu niet werkte. En dan kom je inderdaad in de theorie dat het allemaal fantastisch zou kunnen werken, maar dan moet iedereen het echt willen, en dan moeten we als opdrachtgever ook beseffen dat we als opdrachtgever op een andere manier zo'n project aan kunnen en moeten sturen. Dus meer mensen tegelijkertijd aan tafel, duurdere uren opgeleverd, maar daarmee wel sneller kunnen schakelen, moet je ook durven schakelen, durven beslissen, en kunnen beslissen, wij moeten ook onze eigen organisatie op een andere manier inrichten." (Central information manager, Client, Dutch case, Personal communication, april 10, 2018) **4.1.7.** *"Er is ooit bedacht om met Briefbuilder, ik weet niet of je dat kent? Dat is eigenlijk ook een database programma, waarin je, je moet het zo zien, per ruimte kan inkloppen wat de ontwerp uitgangspunten zijn, dus dat kan zijn, de ruimte temperatuur, of het aantal stopcontacten, of nouja, de hoeveelheid verlichting, de verlichtingssterkte, etcetera, dat wordt dan als data in een model ingevoerd. De gedachte is dan dat je dat koppelt met de data in je model, om te kunnen valideren. Maar dat is een proces dat ook op een bepaald moment losgelaten is in dit project, omdat er eigenlijk, de workflow was*	

	er niet, zeg maar. Dus er is dan een bepaalde tijdsdruk, of het moet bij de opdrachtgever zoals [ziekenhuis] vandaan komen, omdat wij de ontwerpende partijen, ja, die manier van werken is nog niet echt ontstaan. Maar dat zou je wel het liefst willen, he, wat ik ook zeg, de data die aan het model zit, die zou eigenlijk gewoon een bepaalde levenscyclus moeten hebben. Je begint vrij grof, en de hoeveelheid data moet zich dan opbouwen, en het liefst, zonder dat je dingen dubbel doet, en hergebruikt worden in het project. Maar dat is, dat loopt nog niet vlekkeloos." (BIM manager, Client, Dutch case, Personal communication, April 10, 2018)	
RQ5 – Readiness for use, operation and maintanance	Dutch case	Foreign case
Dutch case **5.1.1.** The required information for the use phase should be known.. **5.1.2.** And should be well structured… **5.1.3.** To be used easily for operation and maintenance. **5.1.4.** The BIM model is expected to be interesting for the use phase. **5.1.5.** The difficulty is that the hospital does not know exactly what they want with BIM. **5.1.6.** It is unusual that the hospital uses BIM for maintenance. **5.1.7.** Although, the model is not yet ready for use at this point in time. **Foreign case** **5.2.1.** In the foreign case, the model is not yet ready as well. In general, a difference	**5.1.1.** *"Dat zie je ook in het beheer. We beheren niet wat voor behang er op de muur zit bijvoorbeeld. Dus we beheren ook niet wat voor deur, wat voor cylinder, wat voor sloten, terwijl je wel zou kunnen zeggen dat je dat zou kunnen toevoegen. Dus het zit vooral in installatie componenten. Waar zitten de brandkleppen, en waar zitten de afsluiters, dat soort dingen."* (Project manager, Client, Dutch case, Personal communication, April 10, 2018) **5.1.2**. *"als je in documenten denkt, een duidelijke mappen structuur, wat waar staat en hoe zich dat allemaal tot elkaar verhoudt, en wat dan de status is van het document, en als je over gegevens praat, dan moet het allemaal op de juiste wijze gestructureerd zijn, en op de juiste manier ingevuld. Wij hebben iets van 40 onderdelen die we willen weten, en dan moet je denken aan, is het een object in het model, ofwel een object op tekening wat onderhouden moet worden, wat is dan het*	**5.2.1.** *"Een van de voornaamste reden voor de klant bij het kiezen voor bim is het gebruik van de info in latere fase voor beheer en FM. In [land] hebben we er nog niet direct veel ervaring in, maar het trekt meer en meer aandacht. Ook zijn de FM tools nog niet direct afgestemd op het werken met 3D modellen… Maar grote projecten vergen vele jaren, een klant met visie kiest al voor BIM want binnen enkele jaren zal de FM wereld zeker ver genoeg staan om met de info om te kunnen."* (BIM manager, Foreign party 1, Foreign hospital case, personal communication, May 8, 2018) **5.2.2.** *Ja, maar dan zijn wij niet meer betrokken. […] Eén van de vragen van de klant was, om een fische aan elk object te hangen, als een*

exists in information **5.2.2.** needs of parties from the different phases.	*onderhoudsinterval, zit er nog garantie op, wat voor gegevens komen daar nog meer uit voort. En dat soort gegevens, die vraag stellen we steeds. […] categorieën, en hoe kun je dat dan terugvinden, en als alle pompjes in het gebouw op dezelfde manier pompje heten dan kunnen we ze terugvinden, en daar stellen we eisen aan. En we stellen eisen aan de locatie, dat we altijd weten in welke ruimte iets is, dus gebouw, etage, ruimte. Die drieslag moet er altijd inzitten, want dan kunnen we vanuit onze kant alles in een gebouw selecteren, of alles in een etage of alles in een ruimte, of combinaties daarvan.* (Central information manager, Client, Dutch case, personal communication, November 10, 2017) **5.1.3.** *"Want ja, dan weet je gewoon ook voor onderhoud en beheer veel beter waar iets zit. Want men moet in ons facility management systeem, daar storingen aan kunnen melden, en dan heb je dus op dat niveau iets nodig, in die ruimte doet de deur het niet, ja, welke deur is het dan. […] En er komt een moment in het proces dan heb je de deuren echt gekocht. Dan weten we het wel, en dan moet het er in komen […] En we zeggen hoe het moet. Eerst hadden we daar moeite mee om dat zelf aan te geven hoe we dat moesten doen. En afgelopen half jaar hebben we daar tijd ingestoken om en een lijst aan te geven van deze dingen moet je doen, en die vervolgens ook nog aan te, onder te verdelen per discipline, dus die veertig dingen hebben ook nog eens vier/vijf disciplines in zich dus als je je eigen discipline doe moet je misschien twintig dingen doen. En daar zijn we nu mee bezig, ook een voorbeeld Revitmodel waar we het goed in hebben gezet. Zodat iemand ook een voorbeeld heeft hoe die het moet doen."* 5.1.3. . (Central information manager, Client, Dutch	*lamp het niet meer doet, dat ze hem moeten vervangen*. (Project architect, Foreign party 1, Foreign hospital case, personal communication, April 19, 2018) **5.2.3.** *"Wat heel slecht gaande is, en dan gaat het van de, dat is dan de makkelijkste, dat is van de maakwereld de bouwwereld naar de beheerwereld, dat is, daar hou je heel weinig wrijving over, omdat de beheerwereld eigenlijk nauwelijks of geen eisen stelt aan de data die ze van de bouwwereld willen hebben. Dat is wel heel vreemd, want in feite zeg ik altijd maar, en dat is een klassieker hoor, want dat is vanuit het verleden, als je praat over gebouwbeheer systemen waar ook heel veel informatie ingestopt kan worden, vindt hetzelfde plaats. Wat je ziet is dat, eigenlijk is dat vreemd, want dat is een verschijnsel dat, als je, ontwerpend bouwen is maar 10 of 15 procent van de totale duur van het gebouwde object, en die andere aandeel van procenten is allemaal het beheer. En beheer laat zich te weinig horen van hoe willen wij nou die data regelen, managen en daar uit voort komende eisen waar het op aangeleverd moet worden. En wat je ziet is dat de beheerwereld, dus dat is wel een, vind ik een hele belangrijke, ze zijn eigenlijk gewoon niet vertegenwoordigd in die discussie, echt niet nadrukkelijk genoeg. Eisen hun plek onvoldoende op. Heeft ook te maken dat zij*

	case, personal communication, November 10, 2017) **5.1.4.** *"Het is, het eindproduct zal voor beheer wel interessant zijn. En dan als de overdracht naar beheer wat makkelijker verloopt dan in andere projecten, dan hebben we het goed gedaan. En daar sturen we nu op, maar dat kan, daar krijgen we pas de kans voor in de laatste fase, omdat kennelijk traditioneel iedereen gewend is om dat in de laatste fase, goed oplost. Ik denk dat je dat van begin af aan goed kan organiseren, maar goed, daar hebben we zelf geen sturing in kunnen krijgen. Maar voor nu is het prima, laat het maar gewoon komen. […] Maar ik heb er wel alle hoop op dat we de gegevens gestructureerder en beter aangeleverd krijgen dan, ja, in het verleden met papieren mappen, PDFs of USB sticks, ongestructureerd."* 5.1.4. (Central information manager, Client, Dutch case, personal communication, November 10, 2017) **5.1.5.** Of er aansluiting is: *Jazeker, alleen het lastige bij het [ziekenhuis] is dat zij nog niet precies weten hoe, en dat ze zelf dit nog aan het uitvinden zijn. Zij zijn hier overigens vrij ver mee in het proces maar er blijven altijd nog wat grijze vlakken waar over nagedacht moet worden.* … About the connection between design and use: *"Yes, certainly, the only difficulty is that [hospital] does not yet know how exactly, and that they are still sorting it out. They are quite far with it however, but there are still always some unclear areas which have to be considered."* (Work planner, main contractor, Dutch case, personal communication, June 11, 2018) **5.1.6.** *"Voor wat betreft de werken die [hoofdaannemer] draait is dit een gebruikelijk Proces. Het enige verschil is dat het [ziekenhuis] een*	*weer vastzitten aan onderhoudsbudgetten wat altijd wordt afgeknepen."* *(Project director, 2018) Dat is hun kader waar zij tegenaan knallen. Maar wat ook gebeurt is dat ze vanuit de traditionele wereld in autocad worden getekend en gedaan, en in de beheerwereld wordt dat helemaal gestript. Omdat het eigenlijk gaat om ruimtebeheer en statische planning van wanneer moet ik schilderen en hoeveel oppervlakte is dat. Beetje platgeslagen maar zo zit het wel in mekaar dus in die slag gaat heel veel data ook verloren traditioneel al. En niemand heeft nog een goed antwoord op van de data die beschikbaar is gekomen in de ontwerpperiode, waar nog meer data wordt toegevoegd vanuit de bouwwereld, omdat dan de specifieke data voor de bouwperiode dan ook wordt opgepopt en dan wordt toegevoegd. De aannemer gooit dan ook veel ontwerpinformatie weg. Dat zie je ook, en dan voegt hij zijn eigen ontwerpinformatie toe. En dan wordt dat ook weer weggegooid omdat de beheerwereld weer wat anders wil, dus daar zitten drie delta's zitten er in, twee drie delta stappen.*

	vraag heeft om onderhoud vanuit het model te gaan doen in de toekomst." BIM director, main contractor, Dutch case, personal communication, June 6, 2018) **5.1.7.** "*Nu nog niet, omdat, we zitten nu nog in een fase, vanuit de adviseur richting [ziekenhuis] komt, het moet nog de uitvoering in, maar het is ook onze rol, om er voor te zorgen dat, tijdens de uitvoeringsfase, dat dat model op zo'n manier gevuld wordt, dat het eigenlijk zonder al te veel moeite richting beheer geschoten kan worden. Dus dat er allerlei data uitkomt, een voorbeeld geven: op het moment dat de uitvoeringfase loopt, er is een detail ontwerp gemaakt, van het installatiemodel, want dat hebben we nu voor ons, dat geef ik dan als voorbeeld. Als ik dat rooster aan zou klikken, dan zou ik ook moeten kunnen zien in welke ruimte die zit, hoeveel lucht daar doorheen gaat, en wanneer die voor het laatst onderhoud heeft gehad. Da's bepaalde data, ik noem maar wat, die wil ik dan hebben. Nou, die zou je mee kunnen nemen. Dus we moeten er nu nog voor zorgen dat er een vertaalslag gemaakt wordt, van de generieke informatie die er nu in zit, naar zeg maar de echte as built informatie, die we richting beheer willen. Maar ik zie het wel gebeuren. We hebben nu, ja we hebben, qua eisen die we stellen aan die modellen hebben we het aardig op orde. Dus dat betekent alleen dat het goed gecontroleerd moet worden dat het ook echt gebeurt"* 5.1.5. (BIM manager, Client, Dutch case, personal communication, April 10, 2018)	

Appendix D – Coding in Atlas TI

D.1. Codes used in Atlas TI

A. Connection design-use A1. Ready for use&maintenance A2. Not ready for use&maintenance	I1 – Regular way of working I2 – Irregular way of working	
B1 – Client/end users B2 – Project team B3 – Actors interests B4 – Internal actors B5 – External actors	J1 – Critical factors J2 – Positive aspect/added value J3 – Negative aspect/problem/ possible improvement J4 – Transition/improvement J5 – Expectations J6 – Outcome J7 – Ambition J8 – Change	<u>P. Validation & verification</u> P1.1. Internal P1.2. External – design team P1.3. External, design team & client P2.1. What P2.2. How P2.3. Why P3.1. Set (quality) requirements
C1 - BIM definition – 3D model C2 - BIM defnition – Information management/model C3 - BIM definition – Process C4 BIM definition – collaboration C5 – BIM: what (yes/no, which programme) C6 – BIM: how (way of use) C7 – BIM: why (reasons for use) C8 – BIM agreements/requirements C9 – BIM goals C10 – 2D C11 – 3D C12 - VR	K1 – Manage/ steer /coordinate/ K2 – Project/process/organisation structure K3 – Planning	Q. Costs
D1 – Information/data structure D2 – Data D3 - Needs for information	L. Role/profession	R. Time (available)/ time pressure
E1 – Competences (knowledge/skills) E2 – Learn/teach	M1: Collaboration/team process M2: Work process/way of working	S. Kwaliteit
F. Contract form	N. Software (usability)	T. integral
G1. Communication/information exchange G2. Discussion G3. Agreements (not BIM)	O1. Language (barrier) O2. Hierarchy O3. Rest	
H0. Preparation (phase) H1. Design (phase) H2. Execution (phase) H3. Use & Maintanence (phase)		

D.2. Interviewees: Actors per case and party

Dutch case	**Foreign case**
Client:	Foreign party 1:
1. BIM director	1. BIM manager
2. Project manager	Dutch subcontractor
3. Central information manager	2. Project manager
Main contractor:	3. BIM coordinator MEP
4. BIM director	4. BIM coordinator architecture
5. Planner	5. BIM modeller

D.3. Most mentioned codes in total, per case and per actor group

Most mentioned codes in total	1. B1: Client/end users 2. B2: Project team 3. J3: Problem/possible improvement 4. K1: Manage/steer/coordinate 5. D1: Information/data structure 6. G1: Communication/information exchange 7. C5: BIM - what 8. J4: Transition/improvement 9. . C8: BIM agreements/requirements 10. C6 : BIM - how	
Most mentioned codes per case	**Dutch case** 1. B1: Client/end users 2. B2: Project team 3. K1: Manage/steer/coordinate 4. J3: Problem/possible improvement 5. L: Role/profession 6. C8: BIM agreements/requirements 7. K2: Project/process/organization set-up 8. J2: Positive aspect/added value 9. G1: Communication/information exchange 10. J4: Transition/improvement	**Foreign case** Ten most mentioned: 1. B2: Project team 2. D1: Information/data structure 3. P2.1: Validation - what 4. J3: Problem/possible improvement 5. B1: Client/end users 6. P2.2: Validation - How 7. C5: BIM - what 8. G1: Communication/information exchange 9. C6: BIM - how 10. J4: Transition/improvement
Most mentioned codes for project team vs client	**Project team actors** 1. B2: Project team 2. B1: Client/end users 3. D1: Information/data structuring 4. P2.1: Validation&Verification - what 5. J3: Problem/possible improvement 6. C5: BIM - what 7. G1: Communication/information exchange 8. P2.2: Validation&Verification - how 9. K1: Manage/steer/coordinate 10. J2: Positive aspect/added value	**Client/end users** 1. B1: Client/end users 2. B2: Project team 3. K1: Manage/steer/coordinate 4. J3: Problem/possible improvement 5. K2: Project/process/organization structure 6. L: Role/profession 7. C8: BIM agreements/requirements 8. J4: Transition/improvement 9. C6: BIM - how 10. J2: Positive aspect/added value

Most mentioned codes, by Atlas TI analysis. Underscored codes are different in the top 10. Elaboration in D.4, D.6.1 and D.7.1.

D.4. Density of codes:

"The following codes are mentioned most: (tabel met top top 10 van alles + per casus en per project team/Client) ->See tables X in the appendix.

B1	113	C2	19				
B2	109	C1	19				
J3	78	C7	17				
K1	76	B4	16				
D1	65	S	16				
G1	60	C3	16				
C5	60	C9	15				
J4	57	E2	15				
C8	57	B5	15				
C6	56	E	14				
J2	56	P1.3	14				
P2.1	54	P1.2	14				
K2	53	P1.1	14				
P2.2	51	K	13				
L	49	N	13				
P3.1	40	H2	13			A2	4
C10	40	I2	13			C12	4
A	37	H3	11			O2	3
M1	36	J7	11			G3	2
J1	35	G	11			A1	2
C11	34	C14	10			2D	2
D2	33	T	8			B6	1
J6	33	D3	8			2	1
E1	30	O1	8			D	1
M2	30	I1	8			3D	1
M	28	F	8			J	1
Q	25	J8	7			C13	1
R	24	K3	6			N1	1
H1	24	H0	5			1	1
B3	22	O3	5			O	0
J5	22	C4	4			C3.2	0
P2.3	21	H	4				

Codes most mentioned

1. B1: Client/end users
2. B2: Project team
3. J3: Problem/possible improvement
4. K1: Manage/steer/coordinate
5. D1: Information/data structure
6. G1: Communication/information exchange
7. C5: BIM - what
8. J4: Transition/improvement
9. . C8: BIM agreements/requirements
10. C6 : BIM - how

D.5. Co-occurrence 10 interviews:

Co-occurence tables per research question after coding these 10 interviews

RQ1

To what extent, and in which way is BIM used in the design phase of hospital buildings as a means to share information about the hospital between the design team and the client/end-users of the hospital?

*BIM & communication -> Groep **C**(BIM) met **B**(Actors) & **D&G**(Information) & **I**((Ab)normal way of working)*

BIM (C) vs Actors (B)

	B1	B2	B3	B4	B5	B6
C1	5	5	4	1		1
C10	13	10	5	2	1	
C11	8	6	2	1		1
C12	4	1				
C13						
C14	1					1
C2	3	1	2			1
C3	6	5	2			
C4	1	1				
C5	17	14	2			1
C6	14	15	3			
C7	9	6	1		1	
C8	25	23	6	2	3	
C9	9	3	4	1	2	

Table D.4.1.

➔ Most mentioned together: *BIM agreements (C8) vs Client/end users (B1) and Project team (B2)*

BIM (C) vs Information (D&G)

	D1	D2	D3	G1	G2	G3
C1	7	4	1	3		
C10	9	4	1	8	3	
C11	8	3		4	2	
C12				1		
C13	1					
C14	6	3		2		
C2	11	8	2	2		
C3	4	2	1	5		
C4	1	1				
C5	14	9		10	2	1
C6	15	8	1	10	1	1
C7	2	1	2	2	1	
C8	16	13	4	11		
C9	2	2	1	1		

➔ Most mentioned together: BIM what/how (C5&C6) and agreements (C8) icm Information/datastructurering (D1)

BIM (C) vs Critical factors (I)

	I1	I2
C1	1	
C10		
C11	1	
C12	1	1
C13		
C14		1
C2	1	1
C3		
C4		
C5	2	
C6	1	1
C7		
C8	2	1
C9		

➔ Little co-occurence

RQ2

To which extent is there a well-functioning communication/information sharing between the actors within BIM (e.g. due to their competences) and a well-functioning BIM model (e.g. compatability and interoperability)?

*Groep **C&N**(BIM&software), en **D&G**(Information exchange), met **J**(Kritical factors e.d.)*

BIM&Software (C&N) vs Critical factors (J)

	J1	J2	J3	J4	J5	J6	J7	J8
C1	2	8	3	10	2	3		3
C10	4	14	13	15	4	4	2	2
C11	3	12	12	13	4	3	2	1
C12		1						
C13				1				
C14	1	2		3		2		1
C2		4	3	7	1	2	1	
C3	2	4	3	5		4	1	2
C4	1	1	1	2				
C5	5	9	14	7	1	4	2	2
C6	4	10	10	7	3	5	3	2
C7	3	5	3	2	2	4	1	1
C8	11	10	16	9	4	11	3	3
C9	3	3	7	4	5	3	3	
N		2	9	5	1			

➔ Most mentioned together: BIM agreements (C8) ICM negative aspect/problem/possible improvement (J3), and 2D (C10) vs Transition/improvement (J4).

Information exchange (D&G) vs Critical Factors (J)

	J1	J2	J3	J4	J5	J6	J7	J8
D1	9	10	16	17	6	8	2	2
D2	5	6	13	9	3	3	3	
D3	2	1	3	2				
G1	10	17	14	8	6	13	3	6
G2		1	1					
G3			1			1		1

➔ Most mentioned together: Information/Data structuring (D1) vs Negative aspect/possible improvement (J3) and Transition (J4), and communication (G1) vs Positive aspect (J2) and negative aspect (J3).

RQ3

How is the design and BIM model validated and verified between the project team and the the client/end-user, and how is BIM used in this process?

*Groep **P**(Validation&Verification) met groep **C**, groep **P** met groep **I & J***

BIM (C) vs Validation&Verification (P)

	P1.1	P1.2	P1.3	P2.1	P2.2	P2.3	P3.1
C1				2	1		4
C10	4	2	1	8	9	3	5
C11	3	2	1	7	7	2	2
C12				1	1	1	
C13							
C14				3	3	1	1
C2		1		1	2	1	3
C3				2	2		6
C4			1				
C5	2	1	4	10	8	4	9
C6	1	2	4	12	8	5	8
C7			2	5	5	3	3
C8	3	3	2	7	6	2	16
C9			1	1			4

➔ Most mentioned together: BIM – what (C5) and - how (C6) vs Validation - what (P2.1) and BIM agreements/requirements (C8) vs set requirements (P3.1)

Way of working and Critical factors (I&J) vs Validation&Verification (P)

	P1.1	P1.2	P1.3	P2.1	P2.2	P2.3	P3.1
I1							1
I2			2	2	2	2	1
J1	3		2	5	5	3	5
J2	3		3	9	10	4	5
J3	3	3	3	9	8	4	8
J4			1	4	5	1	6
J5		2	1	3	3	1	3
J6				5	5	2	6
J7							1
J8				1	1		2

➔ Most mentioned together: Positive aspect (J2) vs Validation what and how (P2.1 and P2.2)., and Negative aspect (J3) vs Validation what (P2.1), how (P2.2.) and set requirements (P3.1)

RQ4

In which way does the use of BIM influence the collaboration and work process (positive/negative)?

*Groep **C&J met M***

BIM (C) and critical factors (J) vs Collaboration and work process (M)

	M1	M2
C1	3	1
C10	4	2
C11	4	1
C12		
C13		
C14	1	
C2	1	1
C3	4	2
C4		
C5	4	5
C6	6	7
C7	1	2
C8	8	6
C9	1	
J1	7	6
J2	11	6
J3	9	7
J4	6	7
J5	2	3
J6	4	7
J7		2
J8	3	2

➔ Most mentioned together: team process (M1) with positive point (J2) and negative point/problem/possible improvement (J3), and team process (M1) with set BIM agreements/requirements.

RQ5

To what extent is the BIM ready for use by the client during the operation phase (functional process), and maintenance?

*Groep **C&J** (BIM) met groep **A**.*

BIM (C) and kritical factors (J) with connection design&use and readiness for use (A)

	A	A1	A2
C1	3	1	1
C10	6	1	1
C11	4	1	1
C12			
C13			
C14	1		
C2	4	1	2
C3	2		
C4	1		
C5	3		1
C6	4		1
C7	2		
C8	6		
C9	8	1	
J1	4	1	
J2	5	1	
J3	7	1	1
J4	8	2	2
J5	6	1	
J6	5	1	1
J7	4		1
J8	1		

➔ Most mentioned together: connection design-use (A) with problem/possible improvement and transition/improvement (J4).

D.6. Case comparison

D.6.1. Density per case (mentioned once or more):

Difference in focus: underscore = different in top 10 of codes mentioned. .

Dutch Case

Ten most mentioned:

1. B1: Client/end users
2. B2: Project team
3. K1: Manage/steer/coordinate
4. J3: Problem/possible improvement
5. L: Role/profession
6. C8: BIM agreements/requirements
7. K2: Project/process/organization set-up
8. J2: Positive aspect/added value
9. G1: Communication/information exchange
10. J4: Transition/improvement

B1	78	J5	15	P1.3	5
B2	60	C3	14	C2	5
K1	52	C11	14	G	5
J3	39	S	13	F	5
L	35	E1	13	I1	4
C8	35	H2	12	H	4
K2	35	P2.1	12	H0	4
J2	27	R	12	N	3
G1	27	E2	11	G2	3
J4	26	E	11	J8	3
P3.1	26	C9	11	C12	3
C5	25	Q	10	A2	2
C6	25	K	10	2D	2
J6	23	P1.1	9	K3	2
B3	22	H3	9	D	1
M	21	C7	8	N1	1
M1	20	T	8	3D	1
A	20	P2.3	7	G3	1
H1	19	D3	7	A1	1
D2	18	P1.2	7		
M2	18	I2	7		
D1	18	B5	7		
C10	16	C1	6		
J1	16	J7	6		
P2.2	16	B4	5		

Foreign case

Ten most mentioned:

1. B2: Project team
2. D1: Information/data structure
3. P2.1: Validation - what
4. J3: Problem/possible improvement
5. B1: Client/end users
6. P2.2: Validation - How
7. C5: BIM - what
8. G1: Communication/information exchange
9. C6: BIM - how
10. J4: Transition/improvement

B2	49	P3.1	14	K3	4
D1	47	C1	13	I1	4
P2.1	42	M2	12	F	3
J3	39	R	12	S	3
B1	35	B4	11	E	3
P2.2	35	N	10	K	3
C5	35	C14	10	O2	3
G1	33	J6	10	C3	2
C6	31	C7	9	A2	2
J4	31	P1.3	9	H3	2
J2	29	B5	8	B6	1
K1	24	O1	8	2	1
C10	24	J5	7	D3	1
C8	22	M	7	G3	1
C11	20	P1.2	7	J	1
J1	19	G	6	H2	1
K2	18	I2	6	H0	1
E1	17	H1	5	C12	1
A	17	O3	5	A1	1
M1	16	J7	5	C13	1
Q	15	P1.1	5	G2	1
D2	15	C9	4	1	1
C2	14	J8	4		
L	14	E2	4		
P2.3	14	C4	4		

Quantities of BIM definitions.

BIM codes	BIM codes Dutch case	BIM codes foreign case
Density of codes:	***Density of codes:***	***Density of codes:***

C5	60	
C8	57	
C6	56	
C10	40	
C11	34	
C1	19	
C2	19	
C7	17	
C3	16	
C9	15	
C14	10	
C4	4	
C12	4	
C13	1	

C8	35	
C6	25	
C5	25	
C10	16	
C11	14	
C3	14	
C9	11	
C7	8	
C1	6	
C2	5	
C12	3	

C5	35	
C6	31	
C10	24	
C8	22	
C11	20	
C2	14	
C1	13	
C14	10	
C7	9	
C9	4	
C4	4	
C3	2	
C12	1	
C13	1	

D.6.2. Co-occurrence per case

Dutch case

RQ1 – Dutch case

To what extent, and in which way is BIM used in the design phase of hospital buildings as a means to share information about the hospital between the design team and the client/end-users of the hospital?

*BIM & communication -> Groep **C**(BIM) met **B**(Actors) & **D&G**(Information) & **I**((Ab)normal way of working)*

BIM (C) vs Actors (B)

	B1	B2	B3	B4	B5	B6
C1	3	2	4			
C10	8	5	5	1		
C11	5	3	2	1		
C12	3					
C13						
C14						
C2	2		2			
C3	6	5	2			
C4						
C5	12	10	2			
C6	10	10	3			
C7	5	3	1		1	
C8	21	15	6	1	2	
C9	8	3	4	1	2	

Table D.6.2.

➔ Most mentioned together:
BIM agreements (C8) vs Client/end users (B1) and Project team (B2)

D.6.2. Co-occurrence per case

Foreign case

RQ1 – Foreign case

To what extent, and in which way is BIM used in the design phase of hospital buildings as a means to share information about the hospital between the design team and the client/end-users of the hospital?

*BIM & communication -> Groep **C**(BIM) met **B**(Actors) & **D&G**(Information) & **I**((Ab)normal way of working)*

BIM (C) vs Actors (B)

	B1	B2	B3	B4	B5	B6
C1	2	3		1		1
C10	5	5		1	1	
C11	3	3				1
C12	1	1				
C13						
C14	1					1
C2	1	1				1
C3						
C4	1	1				
C5	5	4				1
C6	4	5				
C7	4	3				
C8	4	8		1	1	
C9	1					

Table D.6.3.

➔ Most mentioned together:
BIM – how (C6) and BIM agreements (C8) vs Project team (B2); 2D vs Client/end-users (B1)

BIM (C) vs Information (D&G)

	D1	D2	D3	G1	G2	G3
C1	1	2	1			
C10	1	3	1	1	2	
C11	1	1		2	2	
C12						
C13						
C14						
C2	1	3	2			
C3	3	2	1	4		
C4						
C5	6	5		6	1	1
C6	5	5	1	6		1
C7	1	1	2	1		
C8	8	9	4	8		
C9	1	2	1	1		

D.6.4.: Most mentioned together: BIM agreements (C8) icm Information/datastructurering (D1), data (D2) and Communication/information exhange

BIM (C) vs Critical factors (I)

	I1	I2
C1		
C10		
C11		
C12		1
C13		
C14		
C2		
C3		
C4		
C5	1	
C6	1	1
C7		
C8	2	1
C9		

D.6.6. Little co-occurrence

BIM (C) vs Information (D&G)

	D1	D2	D3	G1	G2	G3
C1	6	2		3		
C10	8	1		7	1	
C11	7	2		2		
C12				1		
C13	1					
C14	6	3		2		
C2	10	5		2		
C3	1			1		
C4	1	1				
C5	8	4		4	1	
C6	10	3		4	1	
C7	1			1	1	
C8	8	4		3		
C9	1					

Table D.6.5.
Most mentioned together: BIM what/how (C5&C6) and agreements (C8) icm Information/datastructurering (D1)

BIM (C) vs Critical factors (I)

	I1	I2
C1	1	
C10		
C11	1	
C12	1	
C13		
C14		1
C2	1	1
C3		
C4		
C5	1	
C6		
C7		
C8		
C9		

D.6.7: Little co-occurrence

RQ2 – Dutch case

To which extent is there a well-functioning communication/information sharing between the actors within BIM (e.g. due to their competences) and a well-functioning BIM model (e.g. compatability and interoperability)?

*Groep **C&N**(BIM&software), en **D&G**(Information exchange), met **J**(Kritical factors e.d.)*

BIM&Software (C&N) vs Critical factors (J)

	J1	J2	J3	J4	J5	J6	J7	J8
C1	1	2	2	4	1	1		
C10	1	6	7	7	2	1	1	
C11	1	6	6	5	2	1	1	
C12								
C13								
C14								
C2		2	3	2	1	1		
C3	2	3	2	3		3	1	1
C4								
C5	1	2	6	1	1	4		1
C6		3	7	4	2	5	2	1
C7		1	2	1	1	3	1	
C8	8	5	13	5	3	10	2	2
C9	2	3	5	3	5	3	2	
N			2	1				

D.6.8. Most mentioned together: **BIM agreements** (C8) with critical factors (J1), negative aspect/problem/possible improvement (J3) and Outcome (J6)

Information exchange (D&G) vs Critical Factors (J)

	J1	J2	J3	J4	J5	J6	J7	J8
D1	2	3	4	3	2	5	1	1
D2	4	4	9	6	3	2	2	
D3	2	1	2	2				
G1	3	5	4	4	5	9	3	3
G2		1	1					
G3			1			1		1

D.6.9. Most mentioned together: Data (D2) vs Negative aspect/possible improvement (J3) and communication (G1) vs outcome

Still improvements can be made considering data. Also,
In the Dutch case, communication/information exchange is seen as critical for outcome. See table D.6.10.

RQ2 – Foreign case

To which extent is there a well-functioning communication/information sharing between the actors within BIM (e.g. due to their competences) and a well-functioning BIM model (e.g. compatability and interoperability)?

*Groep **C&N**(BIM&software), en **D&G**(Information exchange), met **J**(Kritical factors e.d.)*

BIM&Software (C&N) vs Critical factors (J)

	J1	J2	J3	J4	J5	J6	J7	J8
C1	1	6	1	6	1	2		3
C10	3	8	6	8	2	3	1	2
C11	2	6	6	8	2	2	1	1
C12		1						
C13				1				
C14	1	2		3		2		1
C2		2		5		1	1	
C3		1	1	2		1		1
C4	1	1	1	2				
C5	4	7	8	6			2	1
C6	4	7	3	3	1		1	1
C7	3	4	1	1	1	1		1
C8	3	5	3	4	1	1	1	1
C9	1		2	1			1	
N		2	7	4	1			

D.6.10. Most mentioned together: BIM - what (C5) ICM negative aspect/problem/possible improvement (J3), and 2D (C10) vs positive aspect (J2) Transition/improvement (J4).

Information exchange (D&G) vs Critical Factors (J)

	J1	J2	J3	J4	J5	J6	J7	J8
D1	7	7	12	14	4	3	1	1
D2	1	2	4	3		1	1	
D3			1					
G1	7	12	10	4	1	4		3
G2								
G3								

D.6.11. Most mentioned together: Information/Data structuring (D1) vs Negative aspect/possible improvement (J3) and Transition (J4), and communication (G1) vs Positive aspect (J2) and negative aspect (J3).

In the Foreign case: Structuring data/information is often mentioned as in transition, in which still improvements can be made. See table D.6.11.

RQ3 – Dutch case

How is the design and BIM model validated and verified between the project team and the the client/end-user, and how is BIM used in this process?

*Groep **P**(Validation&Verification) met groep **C**, groep **P** met groep **I & J***

BIM (C) vs Validation&Verification (P)

	P1.1	P1.2	P1.3	P2.1	P2.2	P2.3	P3.1
C1							2
C10	3			1	2	1	3
C11	2			1	2	1	1
C12				1	1	1	
C13							
C14							
C2							2
C3				1	1		4
C4							
C5	1			1	2		7
C6		1		2	1		6
C7				1	1		1
C8	1	1		3	3		12
C9							2

D.6.12. Most mentioned together: BIM – what (C5) vs set requirements (P3.1); BIM agreements/requirements (C8) vs set requirements (P3.1)

Way of working and Critical factors (I&J) vs Validation&Verification (P)

	P1.1	P1.2	P1.3	P2.1	P2.2	P2.3	P3.1
I1							1
I2			1	1	1	1	1
J1	1		1	1	2		4
J2	2		1		3		4
J3	3	2		3	3	2	6
J4					1		3
J5		1			1		2
J6					1		5
J7							1
J8							1

D.6.14. Most mentioned together: Negative aspect (J3) vs set requirements (P3.1)

RQ3 – Foreign case

How is the design and BIM model validated and verified between the project team and the the client/end-user, and how is BIM used in this process?

*Groep **P**(Validation&Verification) met groep **C**, groep **P** met groep **I & J***

BIM (C) vs Validation&Verification (P)

	P1.1	P1.2	P1.3	P2.1	P2.2	P2.3	P3.1
C1				2	1		2
C10	1	2	1	7	7	2	2
C11	1	2	1	6	5	1	1
C12							
C13							
C14				3	3	1	1
C2		1		1	2	1	1
C3				1	1		2
C4			1				
C5	1	1	4	9	6	4	2
C6	1	1	4	10	7	5	2
C7			2	4	4	3	2
C8	2	2	2	4	3	2	4
C9			1	1			2

D.6.13. Most mentioned together: BIM – what (C5) and - how (C6) vs Validation - what (P2.1); BIM how (C6) with validation – how (P2.2); 2D (C10) vs validation what and how (P2.1, P2.2)

Way of working and Critical factors (I&J) vs Validation&Verification (P)

	P1.1	P1.2	P1.3	P2.1	P2.2	P2.3	P3.1
I1							
I2			1	1	1	1	
J1	2		1	4	3	3	1
J2	1		2	9	7	4	1
J3		1	3	6	5	2	2
J4			1	4	4	1	3
J5		1	1	3	2	1	1
J6				5	4	2	1
J7							
J8				1	1		1

D.6.15. Most mentioned together: Positive aspect (J2) vs Validation what and how (P2.1 and P2.2)

***RQ4* – Dutch case**

In which way does the use of BIM influence the collaboration and work process (positive/negative)?

*Groep **C&J** met **M***

BIM (C) and critical factors (J) vs Collaboration and work process (M)

	M1	M2
C1		
C10	1	1
C11	1	1
C12		
C13		
C14		
C2		
C3	4	2
C4		
C5	2	3
C6	4	4
C7		
C8	6	4
C9	1	
J1	3	2
J2	3	3
J3	4	6
J4	3	4
J5	1	2
J6	3	5
J7		1
J8	1	1

D.6.16. Most mentioned together: team process (M1) with set BIM agreements/requirements; work process (M2) with negative point/problem/possible improvement (J3).

RQ4 – Foreign case

In which way does the use of BIM influence the collaboration and work process (positive/negative)?

Groep C&J met M

BIM (C) and critical factors (J) vs Collaboration and work process (M)

	M1	M2
C1	3	1
C10	3	1
C11	3	
C12		
C13		
C14	1	
C2	1	1
C3		
C4		
C5	2	2
C6	2	3
C7	1	2
C8	2	2
C9		
J1	4	4
J2	8	3
J3	5	1
J4	3	3
J5	1	1
J6	1	2
J7		1
J8	2	1

D.6.17. Most mentioned together: team process (M1) with positive point (J2) and negative point/problem/possible improvement (J3)

RQ5 – Dutch case

To what extent is the BIM ready for use by the client during the operation phase (functional process), and maintenance?

*Groep **C&J** (BIM) met groep **A**.*

BIM (C) and kritical factors (J) with connection design&use and readiness for use (A)

	A	A1	A2
C1	2	1	1
C10	4	1	1
C11	2	1	1
C12			
C13			
C14			
C2	2	1	1
C3	1		
C4			
C5	2		1
C6	3		1
C7	2		
C8	4		
C9	7	1	
J1	3		
J2	4	1	
J3	4	1	1
J4	5	1	1
J5	4	1	
J6	2	1	
J7	2		
J8			

D.6.18. Most mentioned together: connection design-use (A) with BIM agreements/requirements (C8), with 2D (C10), with positive aspect (J2), problem/possible improvement (J3), transition/improvement (J4), and expectations (J5).

RQ5 – Foreign case

To what extent is the BIM ready for use by the client during the operation phase (functional process), and maintenance?

*Groep **C&J** (BIM) met groep **A**.*

BIM (C) and kritical factors (J) with connection design&use and readiness for use (A)

	A	A1	A2
C1	1		
C10	2		
C11	2		
C12			
C13			
C14	1		
C2	2		1
C3	1		
C4	1		
C5	1		
C6	1		
C7			
C8	2		
C9	1		
J1	1	1	
J2	1		
J3	3		
J4	3	1	1
J5	2		
J6	3		1
J7	2		1
J8	1		

D.6.19. Most mentioned together: connection design-use (A) with problem/possible improvement (J3) and transition/improvement (J4), and ambition (J7).

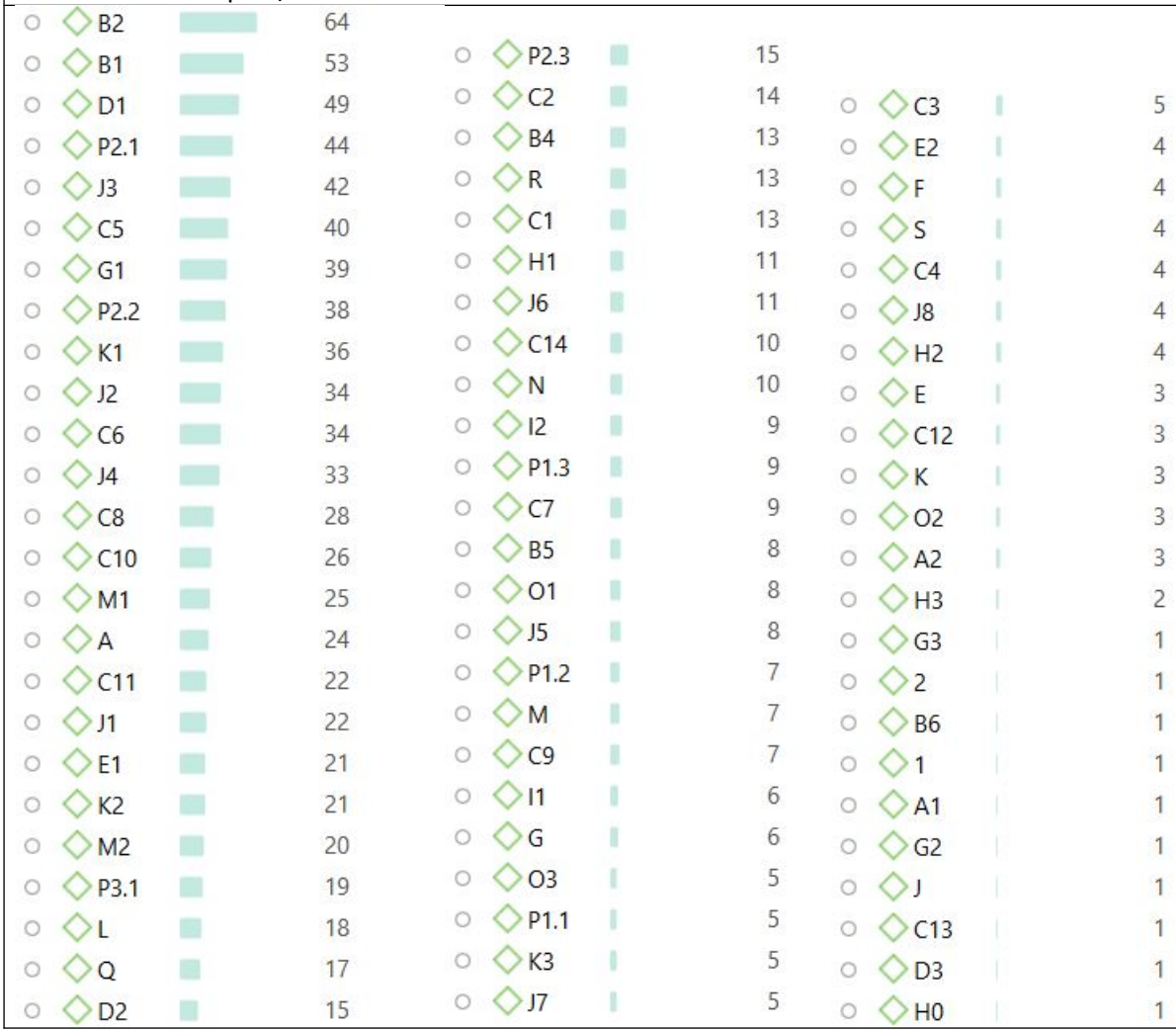
D.7. Analysis – Actors of project team versus client/end-users

In this section, a comparison is shown between actors of the project team and client/end-users.

Project team actors

Ten most mentioned:

1. B2: Project team
2. B1: Client/end users
3. D1: Information/data structuring
4. P2.1: Validation&Verification - what
5. J3: Problem/possible improvement
6. C5: BIM - what
7. G1: Communication/information exchange
8. P2.2: Validation&Verification - how
9. K1: Manage/steer/coordinate
10. J2: Positive aspect/added value



D.7.1. Density per case (mentioned once or more):

Difference in focus: underscore = different codes in top 10.

Client/end-users

Ten most mentioned:

1. B1: Client/end users
2. B2: Project team
3. K1: Manage/steer/coordinate
4. J3: Problem/possible improvement
5. K2: Project/process/organization structure
6. L: Role/profession
7. C8: BIM agreements/requirements
8. J4: Transition/improvement
9. C6: BIM - how
10. J2: Positive aspect/added value

B1	60		C2	5	
B2	45		H0	4	
K1	40		I2	4	
J3	36		F	4	
K2	32		H	4	
L	31		B4	3	
C8	29		G2	3	
J4	24		J8	3	
C6	22		N	3	
J2	22		2D	2	
J6	22		I1	2	
B3	22		D	1	
P3.1	21		N1	1	
G1	21		G3	1	
M	21		A2	1	
C5	20		C12	1	
D2	18		A1	1	
D1	16		3D	1	
C10	14		K3	1	
J5	14				
H1	13				
A	13				
J1	13				
P2.2	13				
C11	12				

D.7.2. Co-occurrence per actor group

Project team

RQ1 – Project team

To what extent, and in which way is BIM used in the design phase of hospital buildings as a means to share information about the hospital between the design team and the client/end-users of the hospital?

*BIM & communication -> Groep **C**(BIM) met **B**(Actors) & **D&G**(Information) & **I**((Ab)normal way of working)*

BIM (C) vs Actors (B)

	B1	B2	B3	B4	B5	B6
C1	2	3		1		1
C10	5	5		1	1	
C11	3	3				1
C12	3	1				
C13						
C14	1					1
C2	1	1				1
C3		1				
C4	1	1				
C5	7	5				1
C6	4	5				
C7	4	3				
C8	7	11		1	1	
C9	3					

➔ Most mentioned together:
BIM agreements (C8) vs Client/end users (B1) and Project team (B2)

Client/end-users

RQ1 – Client/end users

To what extent, and in which way is BIM used in the design phase of hospital buildings as a means to share information about the hospital between the design team and the client/end-users of the hospital?

*BIM & communication -> Groep **C**(BIM) met **B**(Actors) & **D&G**(Information) & **I**((Ab)normal way of working)*

BIM (C) vs Actors (B)

	B1	B2	B3	B4	B5	B6
C1	3	2	4			
C10	8	5	5	1		
C11	5	3	2	1		
C12	1					
C13						
C14						
C2	2		2			
C3	6	4	2			
C4						
C5	10	9	2			
C6	10	10	3			
C7	5	3	1		1	
C8	18	12	6	1	2	
C9	6	3	4	1	2	

➔ Most mentioned together:
BIM agreements (C8) vs Client/end users (B1) and Project team (B2)

BIM (C) vs Information (D&G)

	D1	D2	D3	G1	G2	G3
C1	6	2		3		
C10	8	1		7	1	
C11	7	2		2		
C12				1		
C13	1					
C14	6	3		2		
C2	10	5		2		
C3	2			3		
C4	1	1				
C5	8	4		4	1	
C6	10	3		4	1	
C7	1			1	1	
C8	9	4		4		
C9	1					

➔ Most mentioned together: BIM: information management/model (C2), BIM - how (C6) and agreements (C8) icm Information/datastructurering (D1)

BIM (C) vs Critical factors (I)

	I1	I2
C1	1	
C10		
C11	1	
C12	1	1
C13		
C14		1
C2	1	1
C3		
C4		
C5	1	
C6		
C7		
C8	1	
C9		

➔ Little co-occurrence

BIM (C) vs Information (D&G)

	D1	D2	D3	G1	G2	G3	
C1	1	2	1				
C10	1	3	1	1	2		
C11	1	1		2	2		
C12							
C13							
C14							
C2	1	3	2				
C3	2	2	1	2			
C4							
C5	6	5		6	1	1	
C6	5	5	1	6		1	
C7	1	1	2	1			
C8	7	9	4	7			
C9	1	2	1	1			

➔ Most mentioned together: <u>BIM agreements (C8) icm Information/datastructurering (D1), Data (D2), and communication/information exchange (G1)</u>

BIM (C) vs Critical factors (I)

	I1	I2	
C1			
C10			
C11			
C12			
C13			
C14			
C2			
C3			
C4			
C5	1		
C6	1	1	
C7			
C8	1	1	
C9			

➔ <u>Little co-occurrence</u>

RQ2 – Project team

To which extent is there a well-functioning communication/information sharing between the actors within BIM (e.g. due to their competences) and a well-functioning BIM model (e.g. compatibility and interoperability)?

*Groep **C&N**(BIM&software), en **D&G**(Information exchange), met **J**(Kritical factors e.d.)*

BIM&Software (C&N) vs Critical factors (J)

	J1	J2	J3	J4	J5	J6	J7	J8
C1	1	6	1	6	1	2		3
C10	3	9	6	8	2	3	1	2
C11	2	7	6	8	2	2	1	1
C12		1						
C13				1				
C14	1	2		3		2		1
C2		2		5		1	1	
C3		2	1	2		1		1
C4	1	1	1	2				
C5	4	7	9	6			2	1
C6	4	8	3	3	1		1	1
C7	3	4	1	1	1	1		1
C8	5	5	3	4	1	2	1	1
C9	1		2	1			1	
N		2	7	4	1			

➔ Most mentioned together: BIM - what (C5) with negative aspect/problem/possible improvement (J3); BIM – how (C6) with Positive aspect; 2D (C10) vs positive aspect (J2) Transition/improvement (J4), and 3D (C11) with transition/improvement. .

Information exchange (D&G) vs Critical Factors (J)

	J1	J2	J3	J4	J5	J6	J7	J8
D1	7	7	12	14	4	3	1	1
D2	1	2	4	3		1	1	
D3			1					
G1	8	13	10	4	1	4		3
G2								
G3								

➔ Most mentioned together: Most mentioned together: Information/Data structuring (D1) vs Negative aspect/possible improvement (J3) and Transition (J4), and communication (G1) vs Positive aspect (J2) and negative aspect (J3).

RQ2 – Client/end users

To which extent is there a well-functioning communication/information sharing between the actors within BIM (e.g. due to their competences) and a well-functioning BIM model (e.g. compatibility and interoperability)?

*Groep **C&N**(BIM&software), en **D&G**(Information exchange), met **J**(Kritical factors e.d.)*

BIM&Software (C&N) vs Critical factors (J)

	J1	J2	J3	J4	J5	J6	J7	J8
C1	1	2	2	4	1	1		
C10	1	5	7	7	2	1	1	
C11	1	5	6	5	2	1	1	
C12								
C13								
C14								
C2		2	3	2	1	1		
C3	2	2	2	3		3	1	1
C4								
C5	1	2	5	1	1	4		1
C6		2	7	4	2	5	2	1
C7		1	2	1	1	3	1	
C8	6	5	13	5	3	9	2	2
C9	2	3	5	3	5	3	2	
N			2	1				

➔ Most mentioned together: **BIM agreements** (C8) with negative aspect/problem/possible improvement (J3), with Outcome (J6)

Information exchange (D&G) vs Critical Factors (J)

	J1	J2	J3	J4	J5	J6	J7	J8
D1	2	3	4	3	2	5	1	1
D2	4	4	9	6	3	2	2	
D3	2	1	2	2				
G1	2	4	4	4	5	9	3	3
G2		1	1					
G3			1			1		1

➔ Data (D2) vs Negative aspect/possible improvement (J3) and transition/improvement (J4) and communication/information exchange (G1) vs outcome (J6)

RQ3 – Project team

How is the design and BIM model validated and verified between the project team and the the client/end-user, and how is BIM used in this process?

*Groep **P**(Validation&Verification) met groep **C**, groep **P** met groep **I & J***

BIM (C) vs Validation&Verification (P)

	P1.1	P1.2	P1.3	P2.1	P2.2	P2.3	P3.1
C1				2	1		2
C10	1	2	1	7	7	2	2
C11	1	2	1	6	5	1	1
C12				1	1	1	
C13							
C14				3	3	1	1
C2		1		1	2	1	1
C3				1	1		3
C4			1				
C5	1	1	4	10	6	4	2
C6	1	1	4	10	7	5	2
C7			2	4	4	3	2
C8	2	2	2	4	3	2	8
C9			1	1			2

➔ Most mentioned together: BIM – what (C5) and - how (C6) vs Validation - what (P2.1);

Way of working and Critical factors (I&J) vs Validation&Verification (P)

	P1.1	P1.2	P1.3	P2.1	P2.2	P2.3	P3.1
I1							1
I2			1	2	2	2	
J1	2		1	4	3	3	2
J2	1		2	9	7	4	1
J3		1	3	6	5	2	2
J4			1	4	4	1	3
J5		1	1	3	2	1	1
J6				5	4	2	2
J7							
J8				1	1		1

➔ Most mentioned together: Positive aspect (J2) vs Validation what and how (P2.1 and P2.2)

RQ3 – Client/end users

How is the design and BIM model validated and verified between the project team and the the client/end-user, and how is BIM used in this process?

*Groep **P**(Validation&Verification) met groep **C**, groep **P** met groep **I & J***

BIM (C) vs Validation&Verification (P)

	P1.1	P1.2	P1.3	P2.1	P2.2	P2.3	P3.1
C1							2
C10	3			1	2	1	3
C11	2			1	2	1	1
C12							
C13							
C14							
C2							2
C3				1	1		3
C4							
C5	1				2		7
C6		1		2	1		6
C7				1	1		1
C8	1	1		3	3		8
C9							2

➔ Most mentioned together: BIM – what (C5), BIM how (C6) and BIM agreements/requirements (C8) vs set requirements (P3.1)

Way of working and Critical factors (I&J) vs Validation&Verification (P)

	P1.1	P1.2	P1.3	P2.1	P2.2	P2.3	P3.1
I1							
I2			1				1
J1	1		1	1	2		3
J2	2		1		3		4
J3	3	2		3	3	2	6
J4					1		3
J5		1			1		2
J6					1		4
J7							1
J8							1

➔ Most mentioned together: Negative aspect (J3) vs set requirements (P3.1)

RQ4 – Project team

In which way does the use of BIM influence the collaboration and work process (positive/negative)?

*Groep **C&J** met **M***

BIM (C) and critical factors (J) vs Collaboration and work process (M)

	M1	M2
C1	3	1
C10	3	1
C11	3	
C12		
C13		
C14	1	
C2	1	1
C3	1	1
C4		
C5	2	2
C6	3	4
C7	1	2
C8	3	4
C9		
J1	5	6
J2	10	4
J3	5	1
J4	3	3
J5	1	1
J6	1	2
J7		1
J8	2	1

➔ Most mentioned together: team process (M1) with positive point (J2)

RQ4 – Client/end users

In which way does the use of BIM influence the collaboration and work process (positive/negative)?

***Groep** C&J **met** M*

BIM (C) and critical factors (J) vs Collaboration and work process (M)

	M1	M2	
C1			
C10	1	1	
C11	1	1	
C12			
C13			
C14			
C2			
C3	3	1	
C4			
C5	2	3	
C6	3	3	
C7			
C8	5	2	
C9	1		
J1	2		
J2	1	2	
J3	4	6	
J4	3	4	
J5	1	2	
J6	3	5	
J7		1	
J8	1	1	

➔ Most mentioned together: team process (M1) with set BIM agreements/requirements; work process (M2) with negative point/problem/possible improvement (J3).

RQ5 – Project team

To what extent is the BIM ready for use by the client during the operation phase (functional process), and maintenance?

*Groep **C&J** (BIM) met groep **A**.*

BIM (C) and kritical factors (J) with connection design&use and readiness for use (A)

	A	A1	A2
C1	1		
C10	2		
C11	2		
C12			
C13			
C14	1		
C2	2		1
C3	1		
C4	1		
C5	1		
C6	1		
C7			
C8	2		
C9	4		
J1	1	1	
J2	1		
J3	4		1
J4	4	1	2
J5	3		
J6	3		1
J7	2		1
J8	1		

➔ Most mentioned together: connection design-use (A) with BIM goals (C9) problem/possible improvement and transition/improvement (J4).

RQ5 – Client/end users

To what extent is the BIM ready for use by the client during the operation phase (functional process), and maintenance?

*Groep **C&J** (BIM) met groep **A**.*

BIM (C) and kritical factors (J) with connection design&use and readiness for use (A)

	A	A1	A2
C1	2	1	1
C10	4	1	1
C11	2	1	1
C12			
C13			
C14			
C2	2	1	1
C3	1		
C4			
C5	2		1
C6	3		1
C7	2		
C8	4		
C9	4	1	
J1	3		
J2	4	1	
J3	3	1	
J4	4	1	
J5	3	1	
J6	2	1	
J7	2		
J8			

1. Most mentioned together: connection design-use (A) with BIM agreements/requirements (C8), BIM goals (C9) 2D (C10), positive aspect (J2) and transition/improvement (J4)

Appendix E – Reflection

Aspect 1 the relationship between research and design.

Due to the fact that I am following the MBE (management) track, I did not make a real design, although I set up a list of recommendations for future projects, on basis of the research. I can reflect on the research process, looking at it more as a cyclical process of researching and adjusting the research when gaining more knowledge about the subject, rather dan the relationship between research and a 'real' design. During my research, I did a literature review, and a first session of interviews, to find out what aspects of the subject were relevant in theory ánd in practice. After this, my research question(s) developed in their theoretical and practical relevance. Doing a second round of observations and interviews, with these research questions, led to my final proposal of recommendations for future projects. During the process, I also took into account feedback from my graduation mentor and other professionals (from practice), from my MBE mentors and students of my graduation lab, which could be helpful, in terms of looking at it from another point of view. After the P4, I approached some of the interviewees to reflect on my results and recommendations, as a sort of 'validation of the own research'. This feedback was implemented in the recommendations.

Aspect 2 the relationship between your graduation (project) topic, the studio topic (if applicable), your master track (A,U,BT,LA,MBE), and your master programme (MSc AUBS).

My graduation topic is: communication with BIM in complex projects (observations and interviews on two hospital cases, and extra more exploratory (not included in this report) observation and interviews about a factory, also a complex project).

My main research question is: In what way are the 1) **functionality of the design of hospital buildings, and** 2) **the suitability of the corresponding BIM model** for the **use (phase), validated and verified** between the **various stakeholders,** while making use of **BIM**, and what are the **critical points** toward a **successful process**?

The corresponding **sub questions** are:

1) *To what extent, and in which way is BIM used in the design phase of hospital buildings as a means to share information about the hospital between the design team and the client/end-users of the hospital?*
2) *To which extent is there a well-functioning communication/information sharing between the actors within BIM (e.g. due to their competences) and a well-functioning BIM model (e.g. compatibility and interoperability)?*
3) *How are the design and BIM model validated and verified between the project team and the client/end-user, and how is BIM used in this process?*
4) *In which way does the use of BIM influence the collaboration and work process (positive/negative)?*

5) *To what extent is the BIM ready for use by the client during the operation phase (functional process), and maintenance?*

The main theme of my graduation studio is health care, in which an important topic is user centeredness. My graduation relates to both. Considering health care: I researched the validation and verification, using BIM, of two hospital cases. Considering user-centeredness: In my research, to get a total view of the process, I look at the project team, client and involvement of end-users. So next to the design team and the client (which can be seen as a user all well), the involvement of end-users is investigated in my graduation project.

My graduation relates to my master track (MBE), because I looked into the processes of communication with BIM between various actors that participate in these building projects, which relates to design and construction management, and process management.

My graduation relates also to the master, in a broader sense, because I interviewed all different kind of stakeholders that participate in the building projects: architects, BIM modelers, BIM managers, project managers and also installation and construction professionals. With my graduation I got a broad view and extensive knowledge about BIM, communication and collaboration within the AEC industry.

Aspect 3 Elaboration on research method and approach chosen by the student in relation to the graduation studio methodical line of inquiry, reflecting thereby upon the scientific relevance of the work.

My graduation research method was: an explorative research on basis of case studies. Due to the fact that there was not that much known about my exact topic of study, It was chosen to conduct case studies to find practical examples, in order to conduct a more in depth research about the subject. To analyse the results, grounded theory and senzitings concepts, by means of coding in atlas TI was used. The extensive research method is as follows:

1) First a literature review was conducted, and a first session of observations and interviews were held, to find out what aspects of the research subject were relevant in theory and in practice. My teachers told me it would be good to start with primary interviews early to know also what was experienced in practice, and I think this really helped.
2) After this, from the literature and first interview conclusions, it was defined which sub-topics were relevant to investigate in more detail. The topics were investigated further, by means of literature and interviews. After this second round, the final research questions were formed to conduct the research by observations and in depth interviews in the two case studies.
3) The interviews were fully transcribed, and coded in Atlas TI. This gave some new insights, for example that people mentioned negative aspects more often than positive aspects, thus it could be seen that still a lot of improvements are possible within my the investigated subject.
4) From the conclusions, recommendations were formed to implement in future projects, and for future research. See the report for details.
5) After the P4, interviewees were asked to reflect on their quotes, the conclusion and recommendations, and some even reflected on the full report. This feedback was implemented in the final version of the report.

Looking back at the process, I think my approach worked in the sense that I knew early in the process what was relevant in theory and practice, so my research was going the right way in terms of relevance. The former is emphasized by the extensive interest of interviewees from practice: they were all very interested in my research topic and my report, even people from outside the Netherlands (I investigated one foreign case).

In terms of planning, I think it is very important to arrange things early. Of course, when you investigate a case study, you will always be dependent on the process of the project you follow. I experienced that getting reactions from people from practice could take up to a few weeks (because they are all so busy, and possibly due to other things). For me and the research I think it was just in time, however I experienced quite some pressure close to the deadlines. At the P2, the intention was to do a focus group if possible, but the process demanded otherwise, and instead I asked interviewees to reflect on the almost final report.

I choose to do research on BIM, a technology which is still in development, although from the extensive information I gathered from the interviews I think I really got some answers that can be implemented, or at least be considered, in future projects, as a “best practice”.

With the extensive amount of information I gathered, I found it difficult to extract the most important parts of all the information I gathered. I was really happy with the feedback of everyone, to verify if I mentioned the right things/things right. At the end, I got mostly positive feedback from the interviewees: most had no comments, some had some things to think about, with which I could improve and finalize my report.

Aspect 4 Elaboration on the relationship between the graduation project and the wider social, professional and scientific framework, touching upon the transferability of the project results.

A lot of research has been done, and is currently going on about BIM. It is stated many times how critical the communication (with BIM) is for a successful project and BIM implementation. However, not many research can be found about my exact topic of study. Thus, I think my research really adds something to the information currently available about this topic.

Furthermore BIM is really actual, and more and more companies are implementing it into their projects. During my research, I experienced a lot of interest from interviewees for my graduation topic. Next to their interest for BIM, most of them stated how important communication is, so that is also very relevant. All of them were interested to receive my final results and recommendations. At the end, both organizations of the cases I explored where interested in the results of report I sent them for feedback: of one case they asked to share the results internally and externally, and of the other case, the project director was interested in giving a training to define things better at the start of other projects, based on my results and recommendations. So I think I could say that my research already will be of influence in practice. So, next to the scientific relevance, it also adds to the knowledge of and ways of working by professionals in the AEC industry. .

Aspect 5 Discuss the ethical issues and dilemmas you may have encountered in (i) doing the research, (ii, if applicable) elaborating the design and (iii) potential applications of the results in practice.

i. Because I followed case studies with the involvement of different companies (project partners), I had to be very careful with sharing information. Because they had a working relation, I could say something, but for my own integrity, and to stay on the safe side, I chose mostly to not tell too much about the other cases, other than very general conclusions. Furthermore, I told every interviewee that they could reflect on the quotes, before they get published. I think experiencing this way of being careful with information is really useful for work in practice after my graduation.

ii. N.A.

iii. Most interviewees asked for the final report with recommendations. Based on the beformentioned feedback of the professionals, I think my results will be used in practice for trainings/workshops to improve project processes of communication between various stakeholders who work with BIM, or at least to think about the way they structure their processes now.