Non-graphical Operations and Maintenance data modelling: a case study of a port terminal reconstruction in Tallinn, Estonia

BACHELOR THESIS

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Preface

The last ten weeks I have spent writing this bachelor thesis titled “Non-graphical Operations and Maintenance data modelling: a case study of a port terminal reconstruction in Tallinn, Estonia”. I would have never imagined that I would write my thesis from my home in Tallinn, Estonia, but for many people, including me, the coronavirus outbreak has changed the way they have had to work. It was definitely interesting to get my introduction to online working.

I would like to thank my internal supervisor dr.ir. Leon olde Scholtenhuis who was always available in case I had questions and who always gave constructive feedback that helped me to improve my work a lot.

I would like to thank my external supervisor Miina Karafin from Nordecon AS for helping me during my thesis execution. It was conversations with her that sparked my interest in BIM and her enthusiasm about BIM as a technology and a process that helps the construction industry to take steps further.

I want to thank all the interviewees who gave insight to this project and I especially would like to wish luck to the Port of Tallinn with their goal to develop a fully digital port.

Silver Suurorg

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Summary

Non-graphical data modelling is a significant part of Building Information Modelling (BIM). Non-graphical data plays an important role in the O&M phases of a building's life cycle but is often used in the construction phases as well. To get non-graphical BIM data into the as-built BIM Model in a correct and complete form stated in the BIM requirements, designers and general contractors work on non-graphical data modelling from the preliminary design until the handover. Therefore, it is a long process that needs great collaboration, communication, technological solutions, and coordination.

Prior literature states that clients, general contractors, and designers perceive problems with the process of adding non-graphical data to BIM. For example, clients struggle when defining and prescribing non-graphical data requirements and this could result in a need to change non-graphical data requirements over the course of a project which then brings modelling problems. Second, some of the modelling efforts do not comply with BIM requirements stated by the client and therefore corrections are needed. Clearly, this results in inefficiency, higher labour costs and longer model delivery time. Designers and general contractors lack scientific recommendations and guidelines for non-graphical BIM data modelling. These guidelines could be about the choice of BIM technology; what formats should be used; who is responsible for different parts of modelling process and provision of non-graphical data; when should non-graphical data be linked to the BI model; etc.

Non-graphical BIM data modelling process has been given limited scientific attention in literature, and the goal of this research was to identify the problems and bottlenecks in the process of adding non-graphical data and to provide possible solution directions for these problems. The research question in this thesis asked *what problems occur in the process of adding non-graphical BIM data and which solution directions could improve non-graphical BIM data adding?*

The thesis is a case study of the non-graphical information modelling process that took place in the D Passenger Terminal of the Port of Tallinn reconstruction project in Tallinn, Estonia. The design process of the reconstruction started in 2015, the construction works started 2018, and the project is scheduled to be completed by June 2020. It was one of the first large-scale projects completed with structured and extensive BIM requirements where the client required a large amount of non-graphical data in the as-built model.

The research consists of three main parts: reconstructed process of linking non-graphical data in the port reconstruction case, identification of problems in the modelling process of non-graphical data in the port reconstruction case, and proposal of solution directions. The research data is collected from interviews with the client, the general contractor, and the designer; project BIM requirements; process reflection webinar; observations from process meetings.

In the case-specific process reconstruction, the process of modelling non-graphical data is developed in a chronological sequence. This process model can be used as a reference to contextualise the problems and to determine the origin of some problems. The problem identification was done based on BIM implementation risk factors defined by Chien, Huang & Wu (2014). In prior literature, there was no framework provided to assess the implementation of non-graphical data and therefore aforementioned BIM implementation risk factors were chosen and modified, so they would fit the process of non-graphical data adding.

There were 16 problems identified in the process of adding non-graphical data based on BIM implementation risk factors defined by Chien, Huang & Wu (2014). There were 5 Technical problems,

5 Management problems, 1 Project Environment problem, and 5 Legal problems identified in this study.

The general contractor and the designer argued that the most impactful problem in this project was the change of BIM requirements which was done by the client three times in this project. It was impactful because it caused many other problems (i.e. restructured data is prone for interoperability problems in future; new requirements needed negotiations; etc) in the process of adding non-graphical data. Due to this, significant amount of non-graphical data in the model had to be restructured. Most of the restructuring was manual, time-consuming, and therefore costly.

After the problems were identified, five solution directions were proposed for identified problems. These were proposed by the interviewees and thesis author. Solution directions provided here are broad and should be worked into more detailed suggestions, so that these could be implemented in BIM guidelines in future.

These solution directions are:

- Educated and thorough development process of non-graphical BIM data requirements which is completed before the project execution
- Need to develop Estonian non-graphical BIM data requirements standard
- Need to develop automated technological solutions to discard manual processes in the non-graphical data modelling
- Clients need to have their Operations and Maintenance software selected before defining BI Model data requirements
- Need to educate industry actors on BIM by means of discussions panels, courses, educational material, and standards

These directions provide possible solutions to 14 of the 16 problems identified. These solutions should then be tested in terms of their efficiency in project environments, as this was not done in this thesis. For that, there is need for more research into this topic and generally to non-graphical data as a part of BIM.

The project that was studied might seem very problematic, as 17 problems were found in the process of adding non-graphical data. However, all the interviewees assessed the modelling process as overall positive and considered this project as a great learning environment. One limitation of the study is its predominating perception of the client causing many problems. It should be emphasised that the client was not directly involved in the process, especially in the technical side of it, and for the client it is difficult to defend their position. So, future research could study projects where the client is more involved in the process of modelling non-graphical data.

To conclude, this thesis points on the problems and bottlenecks in the process of modelling non-graphical BIM data. This is an important step towards giving better guidelines for non-graphical data modelling and moving towards an Estonian non-graphical BIM data standard. Hopefully, this thesis contributes to taking this step and moves the construction industry closer towards the standardisation, that is desired by many actors in the field.

Table of Contents

1. Introduction

Architecture, Engineering and Construction industries are implementing Building Information Modelling (BIM) in their design and execution phases. The product of BIM is a Building Information Model (BI Model). A correct BI Model consists of graphical data and non-graphical data. Important factor in the definition of BI Model is that the 3D data only with no object attribute information does not form a BI Model (Eastman, Teicholz, Sacks, & Liston, 2008). In the end of a project, when the building is handed over to the client by the general contractor, the general contractor provides an as-built BI model of a building, so that the client could use it in the Operation and Maintenance phases.

Non-graphical data is a significant part of BIM for Operation and Maintenance, and main contractors lack knowledge and experience when it comes to adding non-graphical data because there has been a low amount of research on this topic. This is evidenced by Pishdad-Bozorgia et al. (2018) who did a broad literature review on case studies of BIM in Facility Management (FM) and in their research, they found that only 2 papers discussed the process of developing FM-enabled BIM.

Prior research states that there are problems with the process of adding non-graphical data to BIM. First, clients that define and prescribe non-graphical data requirements, struggle, because they do not yet know how the facility management team will use the BI Model and its non-graphical data after handover (Anderson, Marsters, Dossick, & Neff, 2012). This could result in a need to change non-graphical data requirements once the client has a clearer idea about these aspects. This results in higher construction management costs and possible information delivery delays. Second, some of the modelling efforts are duplicated by both the architects and general contractors (Pishdad-Bozorgia, Gao, Eastman, & Selfa, 2018). Clearly, this results in inefficiency, higher labour costs and longer model delivery time. Third, facility managers often receive maintenance information in various formats. Due to this, large amount of information in paper or electronic documents must be entered manually to the BI Model or FM systems (Pishdad-Bozorgia, Gao, Eastman, & Selfa, 2018).

Given these inefficiencies, there is a need to make the process of adding non-graphical data more efficient. Therefore, there is a need to first identify problems in the process of adding non-graphical BIM data and based on these, solution directions could be developed and implemented in future guidelines for non-graphical BIM data modelling.

One project that implemented non-graphical O&M data in their BI Model is the reconstruction project of the D Passenger Terminal of the Port of Tallinn. To analyse how problems manifested in this project, this reconstruction was studied as a case. The design process of the reconstruction started in 2015, the construction works started out in June 2018 and the reconstruction is scheduled to be completed by summer 2020. It is one of the first public projects in Estonia that is being completed with non-graphical data requirements that were data-rich and strictly structured in such a large extent. For the client and the general contractor, this was the first project that was completed with this non-graphical data standard and therefore, they lacked experience.

In this thesis, the non-graphical BIM data adding process has been analysed. This report is structured as follows. Literature review, and research design are presented. Results consist of three parts: first part is the process reconstruction of non-graphical data adding in this specific project. second part is the section where problems in the process are identified. Third part proposes solution directions for identified problems. After this, discussion, recommendations, and conclusions are presented.

2. Literature review

2.1. Scientific studies on non-graphical BIM data

BIM (Building Information Modelling) is a technology that can be defined in many ways. BIM handbook defines BIM as "a modelling technology and associated set of processes to produce, communicate, and analyse building models" (Eastman, Teicholz, Sacks, & Liston, 2008, p. 13). The US National Building Information Modelling Standard defines BIM in a following way: "BIM is a digital representation of physical and functional characteristics of a facility." (NBIMS, 2010) The Associated General Contractors of America (AGC) defined BIM as follows: "Building Information Modelling is the development and use of a computer software model to simulate the construction and operation of a facility" (AGC, 2005). Therefore, BIM is not only a software, but more a technology and a process (Azhar, Khalfan, & Maqsood, 2012).

There are many benefits to BIM implementation. According to Azhar (2011), these are:

- Accurate geometrical representation of objects;
- Central information exchange platform where models are shared and modified in a traceable way;
- Ability to analyse designs thoroughly and perform simulations quickly;
- Ability to analyse operational behaviour to predict performance;
- Flexible and automated documentation output;
- Enhanced ability to visualize design alternatives;
- Ability to transfer information from earlier design and construction lifecycle phases (such as, for example, requirements, design information, construction information, and previously completed maintenance information) to operation and maintenance phases.

Shaaban & Nadeem (2015) provide numbers to support benefits of BIM: up to 40% elimination of the unbudgeted change, cost is estimated with an accuracy of 3% and in 80% less time is need for this, contract value is saved up to 10% through clash detections and projects are completed in 7% less time. All these factors contribute to why BIM has been implemented in construction projects more and more.

BIM benefits exist not only for design and construction phases. After the handover (which is the process of handing over a completed building with all the regarding documentation from the contractor to the owner), this data is used for Operation and Maintenance (hereinafter O&M) activities, such as commissioning and close out, quality control, energy management, and maintenance and repair (Yalcinkaya & Singh, 2014). Pishdad-Bozorgia et al. (2018, p. 23) see the ideal BIM model "hold the information for different stakeholders throughout a facility's life cycle" and "provide a reliable facility information database that gives facility managers integrated views from which to retrieve and analyse information efficiently".

Overall, these features contribute to more efficient processes, better designs, savings of an asset's life cycle costs, better stakeholder communication, and re-use of construction operation in the management of operations and maintenance stages.

The product of BIM is a Building Information Model (BI Model). BI Model is an attribute-based, object-oriented and parametric digital representation of the facility (NBIMS, 2010), "forming a

reliable basis for decisions during its life cycle; defined as existing from earliest conception to demolition" (AGC, 2005).

Important factor in the definition of BI Model is that the 3D data only with no object attribute information does not form a BI Model (Eastman, Teicholz, Sacks, & Liston, 2008). Therefore, a correct BI Model consists of graphical data and non-graphical data. Hereinafter, in this thesis, the term non-graphical data is used to refer to attributes. The perception of BIM is generally about the geometrical and graphical benefits of BIM, when in fact, it formulates a small part of modelling (Honti & Erdelyi, 2018). Non-graphical data in BI models formulates the other part of BIM.

Possible non-graphical data that could be included in a BI model are presented in Figure 1. This data is from separate categories. ID and Name are used to identify an object in the model. Service Zone data locates an object in the model. Group and Type data categorizes data to industry- or organization-specific standards. Manufacturer/Vendor data provides information about the origin and usage of an object in the model. Specifications and Attributes give detailed information about an object in the model. Operation and Maintenance data is giving information about the maintenance and operation history of an object in the model.

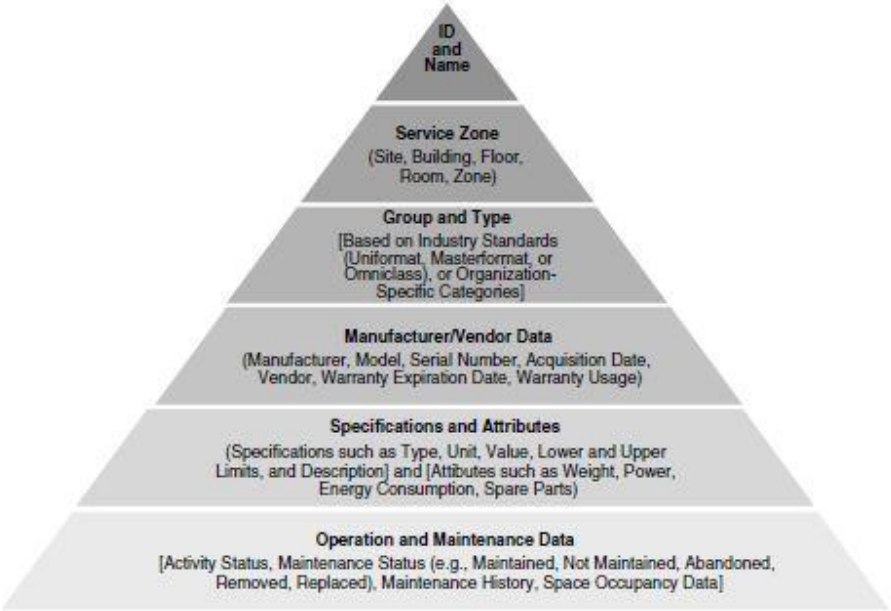

Figure 1. Non-graphical data that could be used in a BI model. (Becerik-Gerber, Jazizadeh, Li, & Calis, 2012)

The process of adding non-graphical data into a BI Model starts already from the procurement. Firstly, the model needs non-graphical data requirements, because models are data-intensive and need structure (Becerik-Gerber, Jazizadeh, Li, & Calis, 2012). For this, the facility manager should be integrated to procurement phase and after this, to design and construction phases as well (Azhar, 2011). Adding non-graphical data should be a client-led innovation because they have the most influence in the civil engineering industry and "research linked to BIM implementation argues for an involved client, actively participating, demanding the technology in procurement and generally influencing its adoption" (Lindblad & Guerrero, 2020, p. 13).

During the design and construction phases, the process of collecting non-graphical data and linking it to BIM needs to be seamless and practical (Pishdad-Bozorgia, Gao, Eastman, & Selfa, 2018). For this, all the involved parties, such as the owner and facility management team, designers, general contractor, key subcontractors and BIM coordinators, need to collaborate at a high level throughout

the design and construction phases while the whole process is tracked by the BIM coordinator (Pishdad-Bozorgia, Gao, Eastman, & Selfa, 2018). Further, the dynamic nature of non-graphical data causes the need for real-time updates of data throughout the construction phase and to have a functional model in O&M stages, as-built conditions should be in the data (Becerik-Gerber, Jazizadeh, Li, & Calis, 2012). Reliable non-graphical data plays a big role in O&M, but there could be barriers if the modelled information is inconsistent (Abdullah, Sulaiman, Latiffi, & David, 2013).

Currently, there are problems with the process of adding non-graphical data to BIM. First, clients that define and prescribe non-graphical data requirements, struggle, because they do not yet know how the facility management team will use the BI Model and its non-graphical data after handover (Anderson, Marsters, Dossick, & Neff, 2012). This could result in a need to change non-graphical data requirements once the client has a clearer idea about these aspects. This results in higher construction management costs and possible information delivery delays. Second, some of the modelling efforts are duplicated by both the architects and general contractors (Pishdad-Bozorgia, Gao, Eastman, & Selfa, 2018). Clearly, this results in inefficiency, higher labour costs and longer model delivery time. Third, facility managers often receive maintenance information in various formats. Due to this, large amount of information in paper or electronic documents must be entered manually to the BI Model or O&M systems (Pishdad-Bozorgia, Gao, Eastman, & Selfa, 2018).

In brief, these process hiccups cause that design requirements for non-graphical data remain unclear, that the model is not yet an effective central source for all the maintenance documentation, leaving it incomplete.

2.2. Non-graphical BIM data implementation risk factors

To clearly identify problems in the process of adding non-graphical data, a structural framework needs to be defined. No exact framework for identifying problems in the process of adding non-graphical data exists. Therefore, the thesis author considered wider BIM implementation assessment frameworks. Chien, Huang & Wu (2014) defined critical risk factors in BIM implementation based on their literature review. Even though these factors do not specifically apply for non-graphical data, these fit well because all important key aspects of non-graphical data adding process are considered and these factors were designed for BIM implementation on a project, not in organisations or in the industry. However, some modifications are made to make the framework more suitable for non-graphical data adding process assessment. These modifications are discussed below.

Chien, Huang & Wu (2014) identified 13 risk factors in BIM implementation. They categorised these 13 risk factors in 5 groups: Technical risks, Management risks, Environmental risks, Financial risks, and Legal risks.

Technical risks consist of four risk factors: Inadequate project experience, Lack of software compatibility, Data management difficulties, and Inefficient data interoperability. (Table 1) These risks are critical for the technical process of adding non-graphical data to BIM. If one of these factors is applicable as a barrier, it is likely that the non-graphical data quality is unsatisfactory.

Table 1. Technical risk factors adapted from Chien, Huang & Wu (2014)

Technical risk	F1 Inadequate project experience	• Actors lack experience with projects that implement non-graphical data in BIM, therefore the unclear business value and unknown risk results could lower the willingness to apply non-graphical data BIM.
	F2 Lack of software compatibility	• Transmission of consistent information to other participants is limited because most project participants are accustomed to working with certain software only. The data, that is missing when transferring from one software to

		another, must be recovered and additional efforts must be made to recover it or add the information with other particular tools. • Software that modellers use is not compatible to automatically add the full extent of required non-graphical data in the model.
	F3 Data management difficulties	• Version control problems will likely occur, as the model is updated throughout execution phases. • Accurate data entry strictly required. • Non-graphical data in the model can be sensitive, therefore the information security must be readjusted. • Software unable to handle large amounts of non-graphical data.
	F4 Inefficient data interoperability	• Data loss might occur when BIM-IFC file exchange is performed or when reading BIM models on distinct software files.

There are three risk factors in the Management risk factors group: Management process change difficulties, Inadequate top management commitment, and Workflow transition difficulties. (Table 2) These risk factors focus on coordinating and guiding the process, dividing responsibility, and collaboration.

Table 2. Management risk factors adapted from Chien, Huang & Wu (2014).

Management Risk	F5 Management process change difficulties	• Design coordinators are not experienced in managing BIM workflow, and have problems clarifying responsibilities for non-graphical data content, thus the process result is an incomplete BI Model. • Reluctance to openly share information. • Liability shifts are likely among project participants.
	F6 Inadequate top management commitment	•Insufficient commitment of top management of contractors and the client leads to problems.
	F7 Workflow transition difficulties	•Lack of ability to integrate traditional 2D workflow process with BIM design tools, leads to ineffective collaboration between people with distinct roles. • Liability shifts are likely among project participants.

Lack of available skilled personnel and Increase in short-term workload are two factors that form the group Project Environment risks. (Table 3) These factors depend on the project where non-graphical data is implemented. These mostly consider the personnel, that is operating in the project, and their skills and knowledge.

Table 3. Project environment risk factors adapted from Chien, Huang & Wu (2014).

Project Environment Risk	F8 Lack of available skilled personnel	• Personnel working on the project does not have established non-graphical data modelling knowledge and ability. • Lack of technical personnel familiar with modelling process.
	F9 Increase in short-term workload	• Compiling a BIM library early in the process increases the initial workload • Using a new software requires a considerable amount of time to get familiar with it. • Existing staff needs to be trained to learn new techniques.

In Table 4, Financial risks are presented. Rise in short-term costs and Additional expenditures are in this risk factor group. These all involve rise in costs that are related to BIM and its non-graphical data implementation in a project. Obviously, all involved actors account for costs that come together with BIM implementation, but risks involve costs that come in as additional during the project.

Table 4. Financial risk factors adapted from Chien, Huang & Wu (2014).

Financial Risk	F10 Rise in short-term costs	• Initial non-graphical BIM data implementation could increase expenses related to data quality review, personnel training, hardware and software acquisition, and other processes.

	F11 Additional expenditures	• Additional funds are required for legal disputes, software updates, and other expense.

Legal and contractual risks form the last group in the categorisation of Chien, Huang & Wu (2014). Lack of BIM guidelines and Unclear legal liability are the factors in this group. Project-specific non-graphical BIM data is based on the contract and other agreements between project parties and for a smooth process of adding non-graphical data these agreements should be clearly defined and completed before the project.

Table 5. Legal or contractual risk factors adapted from Chien, Huang & Wu (2014).

Legal or Contractual Risk	F12 Lack of BIM guidelines	• Lack of clarity about BI Model delivery and acceptance criteria. • Lack of criteria for model building process and design process.
	F13 Unclear legal liability	• Contracts, policies, and other laws of responsibility unclear and still being discussed.

As it can be seen from risk factors, non-graphical data adding process does not only depend on the technical side of it, but other factors need to be well-executed to have a successful process of adding non-graphical data. To assess the process of non-graphical O&M data modelling, the framework provided in Tables 1-5 gives a lens to identify problems in the process of adding non-graphical data.

2.3. Problem definition and research question

In sum, scientific literature presents only a few studies that analyse the process of adding non-graphical data to BIM in projects and because of that, problems in the process of adding non-graphical data have not been discussed in literature. Lack of case studies that show good practices, are a likely cause for the current problems and bottlenecks. Studying the processes of non-graphical O&M data modelling would help understand how guidelines can be developed to better support this modelling process. Identification of process needs and bottlenecks therefore is essential to enhance the modelling practices in future.

From the problem definition and background information, the main research question is defined:

What problems occur in the process of adding non-graphical BIM data and which solution directions could improve non-graphical BIM data adding?

3. Research

3.1. Case study description

The thesis is a case study of reconstruction of the D Passenger Terminal of the Port of Tallinn (Figure 2 and Figure 3). The design process of the reconstruction started in 2015 (Penjam, 2019). The construction works started out in June 2018 and are carried out by the thesis host organisation, main contractor Nordecon AS (Whyte, 2018). It is a reconstruction in two phases: the first phase was completed in October and the second phase is scheduled to be completed by summer 2020 (Wright, 2019).

Figure 2. D passenger terminal of the Port of Tallinn.

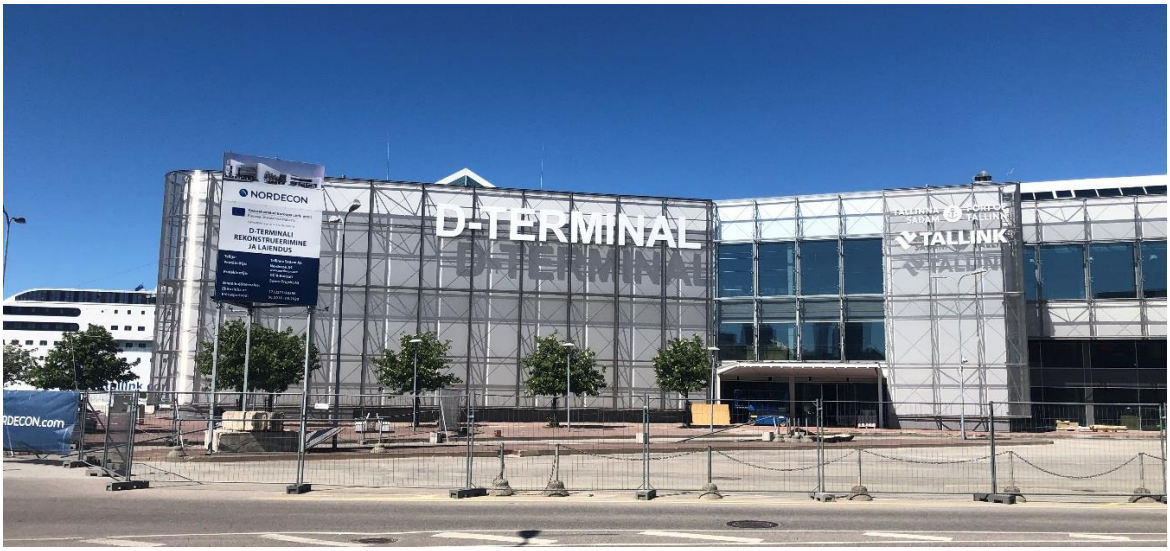

Figure 3. D passenger terminal of the Port of Tallinn.

The architectural design of the building has been done by R-Konsult OÜ. The engineering design was done by Sweco Projekt AS. The general contractor in this project is the thesis host organisation Nordecon AS. It is a four-storey building with floor area of 14 000 m^2 and it is built to service 6 million passengers in a year. In the Estonian construction sector, this is considered a large-scale project.

The non-graphical data requirements in BIM used in the project are project-specific requirements that have been worked out by the client and are based on the 2018 RKAS (RKAS – State Real Estate Ltd. – is a company that operates state-owned buildings. RKAS BIM requirements are widely used in the Estonian construction industry) standard. However, there were several changes in non-graphical data requirements during design and construction phases. As the project execution started around the time when the implementation of 2018 RKAS standard had just started, then it is one of the first public projects that is being completed with non-graphical data requirements that were data-rich and strictly structured in such a large extent. For both, the client and the general contractor, this was the first project with this non-graphical data standard.

With their BIM requirements, the client demanded an as-built model at the handover, so they could use it in O&M. The as-built model had structured and extensive non-graphical data content requirements. However, these same requirements were not set from the beginning of project but were in fact implemented during the construction stage. This caused a significant amount of re-modelling and many of the risks described by Chien, Huang & Wu (2014) occurred in this project. Together with the fact that it is one of the first projects completed with this 2018 RKAS standard makes it a case which process needs to be examined to identify problems in the process of adding non-graphical BIM data.

3.2. Methodology

The research consists of three main parts: Reconstructed process of linking non-graphical data, Identification of problems in the process of adding non-graphical data, and Proposal of solution directions. The information for research is collected from interviews with the client, the general contractor, and the designer; project BIM requirements; process reflection webinar; observations from process meetings. This has been visualised in Figure 4.

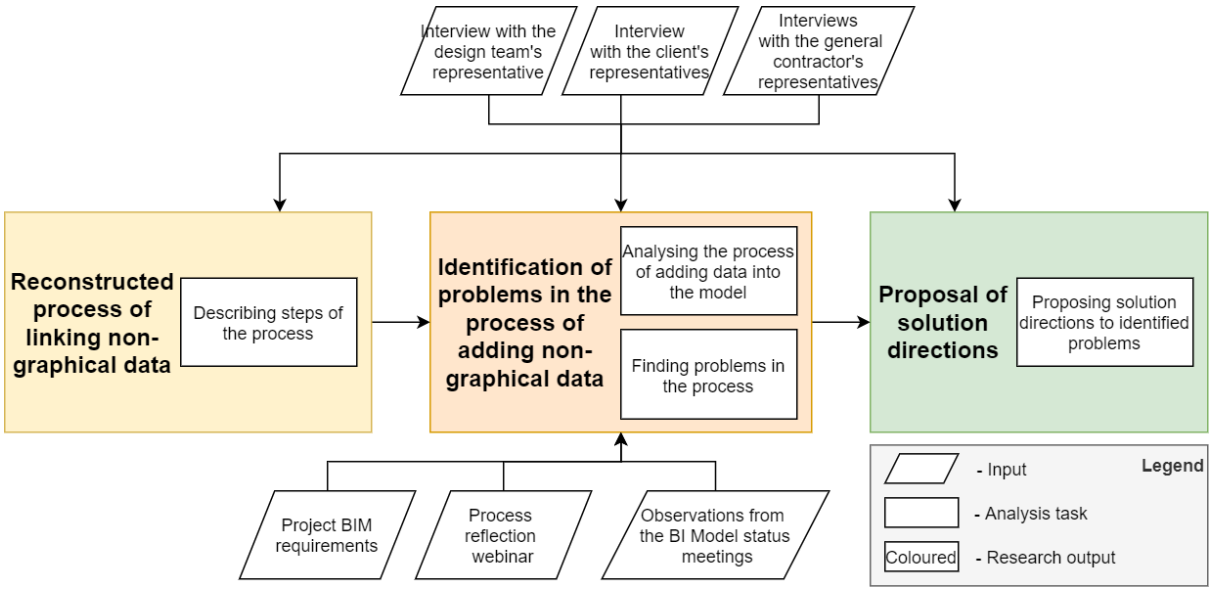

Figure 4. Thesis research design.

Data collection methods and analysis steps are now further elaborated.

3.2.1. Data collection

There were four interviews held with project participants (Table 6). They were interviewed to reconstruct the process of adding non-graphical data in this project and to find out their view on the process of linking non-graphical data to the BIM model. These people were asked questions about following aspects: communication, coordination, planning, technological aspects, model quality, reflection on the process – all defined as critical aspects of non-graphical BIM data adding process based on the literature review, including the risk factors of Chien, Huang & Wu (2014). Exact interview questions are presented in Appendix A with additional details about interviews. The transcripts of interviews are not presented in this thesis and the interviewees are kept anonymous.

Table 6. Summary of conducted interviews.

Interview	Interviewee(s)
Interview A	Two BIM coordinators from the general contractor
Interview B	The lead engineer from the engineering design firm
Interview C	A BIM coordinator from the general contractor
Interview D	Two representatives from the development department of the client

In interview A, two representatives from the general contractor were interviewed. They worked on this project as BIM and construction working design coordinators. They were interviewed because they represented the general contractor in all BIM-related discussions in the project and were familiar with the process of adding non-graphical data, on which the interview focused on.

Interview B was conducted with a designer. The interviewee was the lead engineer for the project design team who was representing the firm in BIM and design negotiations and was involved in the modelling process as well. Initially, the design team representative was not intended to be interviewed, however, during the execution of the thesis it turned out that the client was not as much involved in the process of adding non-graphical data as expected, then the design team representative was interviewed.

Interview C was conducted again with the general contractor. One of the two interviewees from interview A was interviewed again about the problems in the process because due to time-related reasons there was not enough time during the first interview to focus on the problems in the process of adding non-graphical data.

In interview D, two people from the development department of the client were interviewed. One of them was the one who had the idea of implementing BIM in this project and was well-informed about BIM process in the project and the other interviewee worked on the development of client's BIM requirements.

Another input for the research was a public online event (hereinafter as the webinar) hosted as a pre-event for World Summit on Digitally Built Environment where D terminal project parties reflected on the process of BIM implementation in this project. This focused widely on BIM implementation in the port reconstruction, but non-graphical data processes were reflected on in this webinar as well.

Additionally, there was project documentation used such as BIM requirements set by the client and official meeting notes from construction design meetings. These were provided to the thesis author by the general contractor.

What is more, the thesis author was invited to two online (due to COVID-19 lockdown) meetings where the discussion topic was the state of the as-built model and its non-graphical data. There the author was able to make observations about the communication of project parties and determine problematic parts of the process. These observations can provide information about problems from the outside perspective – problems that interviewees might have not noticed.

3.2.2. Analysis methods

In the process reconstruction, the process of adding non-graphical data is developed in a chronological sequence. This has been done based on interviews with representatives from the general contractor, an interview with a representative from the design team, and an interview with the client's representatives. The process reconstruction is case-specific and the goal of this process reconstruction is to sequence all the actions and steps that were done to add the non-graphical data to the BI Model. This process model can be used as a reference to contextualise the problems and to determine the origin of some problems.

The identification of problems and bottlenecks in the process of linking non-graphical data into the BI Model will be done based on all interviews, observations from the webinar, and BIM requirements analysis. These problems are categorised by the framework provided by Chien, Huang & Wu (2014) and which was presented in the chapter Non-graphical BIM data implementation risk factors. There were five categories presented in this chapter, however problems in this thesis are presented in only four categories, leaving out the category of financial problems. This was done because financial records of project parties were not presented to the thesis author, and therefore it was not possible to determine the exact extent of financial losses and which project party was the one covering those losses from their budget.

After the problems have been identified, the solution directions for these problems are presented. These solution directions are proposed by the thesis author and interviewees, and the interviewees' comments are added in this section. These solutions are recommendations for future large-scale projects where non-graphical data is implemented in BIM.

4. Results

4.1. Reconstructed process of linking non-graphical data

The process of linking non-graphical data into the BI Model is reconstructed in this chapter. This process has been reconstructed in Figure 5 and is more elaborated in the following section.

The project started in 2014. First project phases were executed without any BIM requirements concerning the non-graphical data in BI Models. Client organised the architectural and engineering design public procurement in 2015, which included no BIM requirements. Only BIM-related aspects in the procurement were 3D design, but no requirements about informational content were mentioned. The design team joined the project and started working on the preliminary design. As there were no non-graphical data requirements, there was no non-graphical data adding done at the time.

Halfway into the preliminary design phase, the client decided to reconstruct the D-terminal in a greater extent and according to public procurement law, this needed a new public procurement. Client organised the new design public procurement in 2015, which included the COBIM 2012 and LOD 300 requirements. COBIM 2012 is the Finnish standard BIM requirement (buildingSmart Finland, 2012) and LOD 300 is an international reference for BIM practice (BIMForum, 2019). Since the start of the project, the client had learnt more about BIM and decided to implement these standard BIM requirements to their procurement. However, they were not educated enough to develop their own BIM requirements and did not yet see the development of these as beneficial. The same design firm won the public procurement and the design team continued with the modelling process. From this point on, there were non-graphical data requirements, but according to interviewees, these required significantly less data compared to requirements that were used later (client's own requirements) in the project.

Designers created model elements in the original file format and linked all the required non-graphical data fields (if it was possible technically) to model elements based on the BIM requirements. This worked in a way that a model element was added to the model and linked to it appeared a table for non-graphical data content. This was done in two ways: either by creating an element from scratch and adding all the necessary non-graphical data fields manually, or using an element provided from the software database and in the database it already had non-graphical data fields linked to it. Latter was preferred by designers because it is quicker, but software-provided elements might not contain all the necessary data fields, as the non-graphical data fields for elements are dependent on which non-graphical data has been deemed necessary by software developers.

Creating an element with its non-graphical data structure was a crucial step in this project because the same model that was started with, was made more detailed throughout the project. Therefore, model elements needed to be structured in a way that was compatible with the as-built model requirements for model elements, because afterwards, restructuring the model was in essence erasing and recreating the same elements, which was very time-consuming and manual, because data from the erased element could not be transferred to the new element.

During the preliminary design phase, designers filled non-graphical data fields with desired parameters for model elements. These parameters are based on engineering decisions and calculations. For example, for a radiator, the desired power in kW is filled in based on the engineering calculations. Later in the construction phase, the general contractor uses those values to choose products or materials for the building.

With these procedures, the detailed design was completed. Then in 2018, the client organised the public procurement for finding a general contractor. In the procurement, there were RKAS 2016 BIM requirements for the as-built model that the general contractor needed to deliver.

After winning the public procurement, the general contractor made a contract with the design firm, where the BIM requirements from the general contractor were used when making the construction working design. BIM requirements from the general contractor were necessary because the RKAS 2016 BIM requirements were insufficient for supporting the construction process, while the general contractor's BIM requirements were structured and more extensive. The general contractor's requirements help them efficiently choose products for the building based on modelled non-graphical data about the element, help them calculate the amounts of material that they need, and support the installation works of elements. In June 2018, the general contractor started with construction works.

Around the time when the construction works started, the client decided to work towards their own BIM requirements. The client had implemented RKAS 2016 requirements, but they felt that these did not actually help them for their O&M needs. They wanted to work towards their own requirements which would help them operate the building better. For that they gathered their facility managers and asked them for input on which attributes they would need in O&M. Additionally, they hired a consultant and they consulted with the general contractor, who was also getting input from designers. All of them gave their input for the BIM requirements based on their experience and knowledge. The non-graphical data linking for the as-built model was mostly stopped until the client came out with their own BIM requirements. Only non-graphical data needed based on the Nordecon BIM requirements was added to the construction working design model to support the construction works.

Meanwhile, the construction works were happening. The general contractor started ordering products for the building and they used those technical parameters of elements for the choosing process. If they had chosen a product and it was approved by the client, the non-graphical data about this product was communicated to the design team and they updated or added the product-specific non-graphical data to already existing attribute fields. Some of the fields that were previously empty, for instance supplier, can now be added as well. To summarize, the design team fills attribute fields with the required non-graphical data in each phase with phase-specific data extent. Before the products are chosen, performance design parameters of elements are added to attribute fields. Until the product-specific information such as supplier or other product-specific characteristics appear in the model, these values are designed parameters that the general contractor can use to select products. The general contractor's responsibility is to provide the product-specific information and changes in design.

Changes in design might be proposed by the general contractor or subcontractors for technological, functional, or financial reasons. If a sub-contractor or the general contractor wanted to make a change in the design, and if this was accepted by the client and the supervisors, then the change was forwarded to the designer, who modelled the change and updated the non-graphical data in the BI Model.

In December 2018, the client finished their own BIM requirements, which were much more extensive than the previous requirements regarding the O&M-needed content. The general contractor's requirements were less focused on this because these were mostly meant to support the construction process. The model needed to be restructured which means that most of it was erasing and recreating the elements again with the required non-graphical data. The design team

made the price offer to the client about the adding process of new required non-graphical data in the original file format. Significantly cheaper alternative of making the model comply with the new requirements was using a BIM data editing software, which allows to add/edit the new non-graphical data in the IFC format. For this, the general contractor made a contract with BIM solutions subcontractor, who started the IFC quality control and the process of adding the required non-graphical data using their own template, that they had created, and a BIM data editing software.

Product information sheets and user manuals, which were stored in the folder tree of as-built documentation, were added to the model by the general contractor or the BIM subcontractor throughout the project.

Before the handover, the as-built model and its non-graphical data content was checked and then will be handed over to the client. If the model was incorrect or incomplete, faulty parts were noted and communicated to the design team and they added the missing non-graphical data. This was done until the model was complete and had the correct non-graphical data. Afterwards, the model will be handed over to the client. Client will check the as-built model and if approved based on the model requirements, uses it for O&M purposes.

*The thesis execution ended in May 2020, but the expected date of handover is in June 2020.

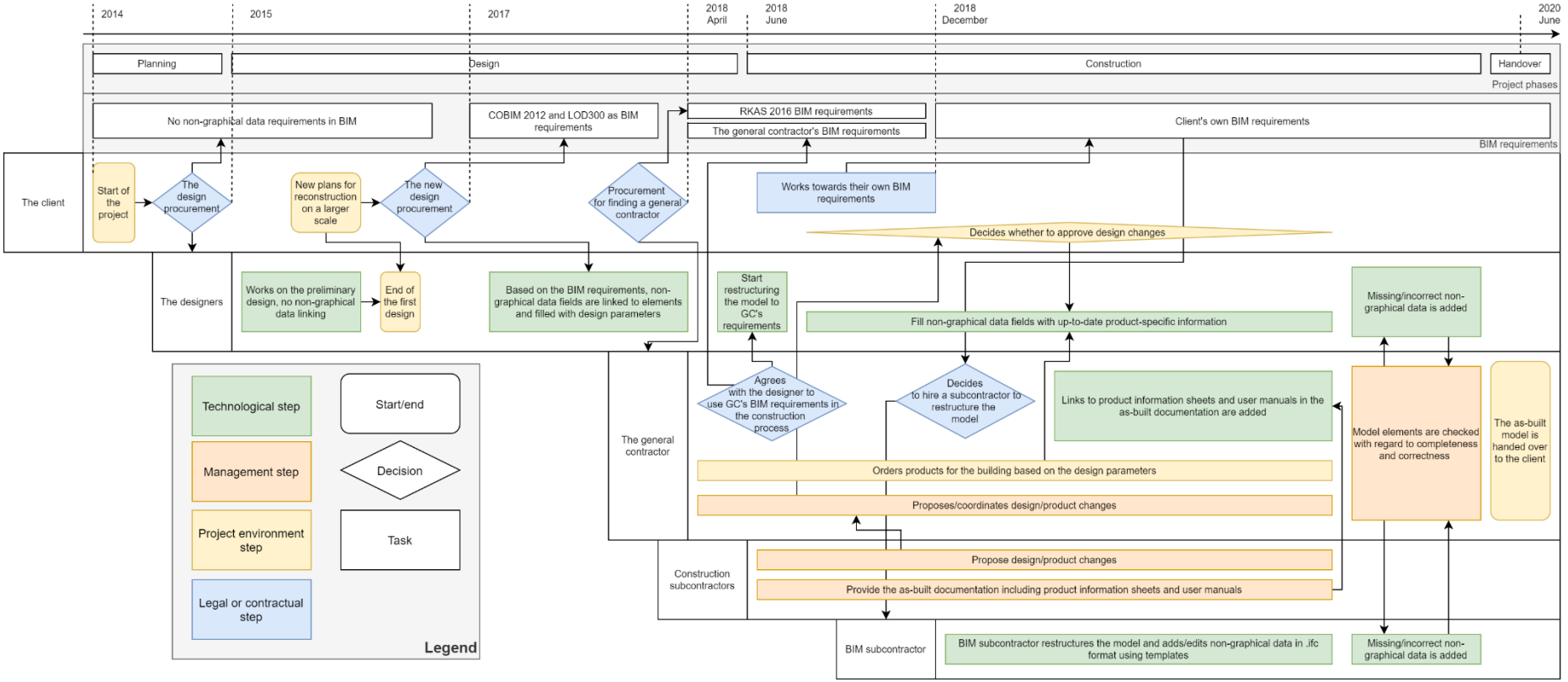

Figure 5. The process of adding non-graphical data to BI models in the project.

4.2. Identified problems in the non-graphical data modelling process in the project

The problems that were identified in the process of adding non-graphical data are presented and elaborated in this chapter.

16 problems were identified in the analysis and there were 5 technical problems, 5 management problems, 1 project environment problem, and 5 legal and contractual problems identified. These are presented in Figure 6.

The general contractor perceived the most problems in the process of adding non-graphical data. This is because they were responsible for delivering the as-built model, but they joined the project later than the designer and therefore, most of the modelling had been done already. They could not influence the modelling process before and then they had to restructure and coordinate in a large extent.

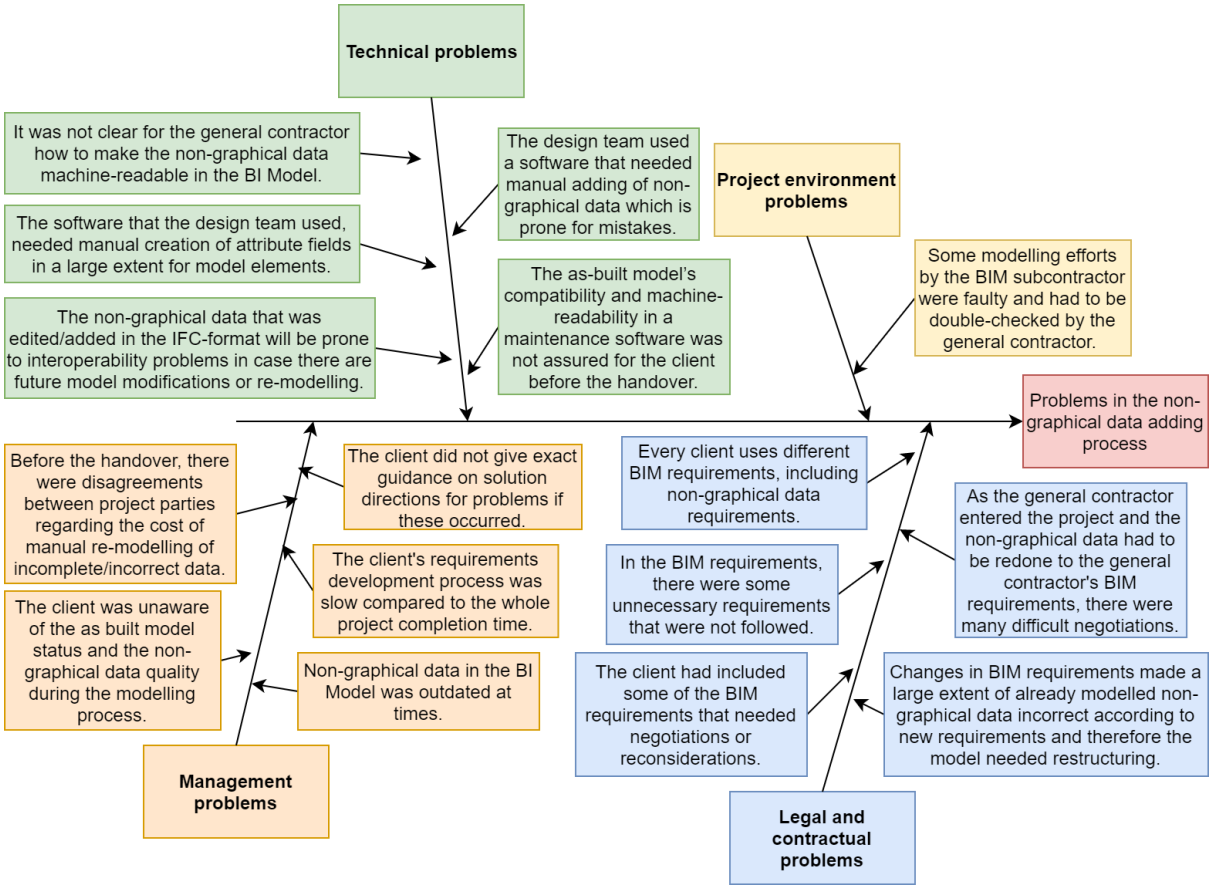

Figure 6. Problems in the process of adding non-graphical data.

Problems that were identified in the analysis and are presented in Figure 6 are now further elaborated in next subchapters.

4.2.1. Technical problems

Problem T1
The software that the design team used, needed manual creation of attribute fields in a large extent for model elements.

Databases in the BIM softwares that the design firm used were very limited. Many of the elements in the model had to be created manually for them to be able to link all the required non-graphical data

to those same elements. Engineers in design teams focused on creating elements and giving them attributes instead of coming up with actual engineering solutions, which was essentially their job in the process. Therefore, it was frustrating for designers, it was expensive and it was not efficient due to manual process.

Problem T2
The design team used a software that needed manual adding of non-graphical data which is prone for mistakes.

The design team used a software which needed a significant amount of manual non-graphical data adding. In addition to manual adding of non-graphical data being time-consuming, it was prone for mistakes as well, because designers made humanly mistakes as the data amount was vast. Since it was prone for mistakes, manually entered data needed additional checks to find and edit mistakes by designers and checking was additional workload and therefore an additional cost.

Problem T3
The as-built model's compatibility and machine-readability in a maintenance software was not assured for the client before the handover.

The client was not able to test the as-built model and its non-graphical data in a maintenance software because they had yet not chosen the software that they were going to use. They were moving towards digitizing their property management not only for the D-terminal but for all the port-owned properties and for this, they were looking for a good software that would fit their demands. Without knowing the exact software, it was not sure whether the BI Model was compatible, and its data was machine-readable. Before the handover, the general contractor just followed the requirements and guidelines for the as-built model that the client had provided but testing of the model could not be done.

Problem T4
It was not clear for the general contractor how to make the non-graphical data machine-readable in the BI Model.

For the general contractor, it was not clear in which format should have the non-graphical data been added into the as-built BI Model. For example, which attributes could have been added as text, which attributes needed to be entered as numbers. If the data is not machine-readable for the software where it will be opened, it needs to be overwritten in the right format or errors might occur.

Problem T5
The non-graphical data that was edited/added in the IFC-format will be prone to interoperability problems in case there are future model modifications or re-modelling.

As the BIM requirements changed, adding/editing non-graphical data with templates in the IFC file format was chosen as the method to make the model match the new requirements. Generally, non-graphical data is added automatically in the original file format because model elements in the original software database have most of the necessary non-graphical data fields and some fields can be filled with data content automatically. The original file format is exported from the modelling software into the IFC file format so it is compatible with other submodels of a building and can be

viewed in BIM softwares. Preferable is to add/edit non-graphical data in the original file format, but this would have been expensive in this project. As the IFC editing was chosen, data compatibility problems might occur in the future when model might be modified or re-modelled, because in essence, IFC editing is overwriting non-graphical data from an original software and now it needs to be overwritten again in case there are changes.

4.2.2. Management problems

Problem M1
The client was unaware of the as built model status and the non-graphical data quality during the modelling process.

The client felt that they were not involved in the process of adding non-graphical data. Due to that, the client was not aware of the status of the non-graphical data in the BI Model and in case they wished to make any changes to get a better as-built model at the handover, it was not possible. Understandably, the client had defined BIM requirements and their wishes for the as-built model should have been reflected in the BIM requirements but during the development of BIM requirements there could have been unforeseeable aspects of non-graphical data that could have been prevented at an early stage if the client would have been included in the process of adding non-graphical data. The client asked for the as-built model during the construction phase, but the general contractor persuaded that it is most feasible to present the full as-built model right before the handover when all the non-graphical data complies with requirements. On the other hand, the client did not have a method to validate the non-graphical data in the model and even if the general contractor would have provided the as-built model, they client could not have been able to give feedback on it. The client was not completely unaware of the non-graphical data status in the BI Model, as in the design meetings the BI model was the visual communication tool, the client was able to see some of the non-graphical data that was in the model, but the non-graphical data was not checked methodically there.

Problem M2
Before the handover, there were disagreements between project parties regarding the cost of manual re-modelling of incomplete/incorrect data.

Before the handover, there was a recurring process of finding incomplete/incorrect non-graphical data in the model. Incomplete/incorrect data was in the model because it was either not modelled from the beginning, there were construction design changes that went uncommunicated, there had been communication errors, responsibilities for model content had been unclear, or simply there had been mistakes made by people who inserted data manually – so in short, modelling process had not been well-coordinated and therefore model quality needed improvements. Incorrect or incomplete data needed to be corrected. This recurring process was between project parties and includes meetings, email conversations and visual model communication tools. This process was time-consuming and often it was difficult to come to agreement which project party had to cover the cost of adding/editing incomplete/incorrect non-graphical data because it was an expense that none of the project parties had included in their budgets.

Problem M3
The client did not give exact guidance on solution directions for problems if these occurred.

There were many contractual changes during the project which were reasons for issues concerning BIM. If these issues arose, the client was asked about possible directions to solve these problems. Due to their inexperience, the client did not know what they want in a solution for a problem. Instead, the client asked the general contractor or designers about their experience in similar problems, so they would need to advise the client about what is the best possible option for the client based on their experience with other clients. However, the designer's and the general contractor's experience might have not provided the best solution for this specific client and in future the client might have an as-built model that does not exactly suffice their needs.

Problem M4
The client's requirements development process was slow compared to the whole project completion time.

The client initially had the idea of working out their own BIM requirements at the time of construction procurement but the development of these was started four months later when the construction works started. After this, the client worked on their own BIM requirements for six months. As the construction works lasted about two years, it means that the first quarter of the construction works the BIM requirements were not set. The first quarter of construction was the time when most of the construction design changes were implemented by the general contractor and for BIM, this involved a significant amount of re-modelling. As the BIM requirements were still worked out, the re-modelling needed to be redone once again when the final requirements had been set.

Problem M5
Non-graphical data in the BI Model was outdated at times.

If there were changes made in the design and consequently the non-graphical data had to be updated, sometimes not all the involved parties received the information about the change. For example, if architects made some changes, then MEP engineers reached the information later or they had to find it out themselves from the designs. This caused the non-graphical data in the model to be inaccurate and outdated at times during the process. Consequently, modelling delays occurred, there was a need to redesign, and it created tensions between project parties.

4.2.3. Project environment problems

Problem E1
Some modelling efforts by the BIM subcontractor were faulty and had to be double-checked by the general contractor.

The general contractor hired a BIM subcontractor that was supposed to add/edit non-graphical data in the model with templates and a BIM data editing software. The general contractor hoped to receive good quality from the BIM subcontractor but still they had to do additional work to check the non-graphical data quality because due to the BIM subcontractor's lack of experience, they sometimes made mistakes. For example, they categorised model elements based on same IFC-

attribute and added a product specific performance value for all the elements in this categorisation. However, elements in this categorisation might have had different values as products differed. At the time of hiring a BIM subcontractor, there were only few other competing BIM solutions contractors. Lack of competition and lack of experienced BIM solutions contractors is a problem in the Estonian market.

4.2.4. Legal and contractual problems

Problem L1
Changes in BIM requirements made a large extent of already modelled non-graphical data incorrect according to new requirements and therefore the model needed restructuring.

The designer and the general contractor argued that this problem was the most impactful problem in the project and caused many other problems. The client learnt about BIM throughout the project and with their new knowledge, they decided to look for new requirements. The client changed their BIM requirements three times during the project. All the changes included non-graphical data requirements changes. After changes, the non-graphical data had to be restructured, added or edited because already modelled parts of the BI Model were then incorrect. Restructuring was mostly manual and included a lot of re-modelling in the original software and that brought additional costs and delayed the process of adding non-graphical data. This process in the original software was very inefficient – a model element was erased and then remodelled with new attributes that were required with new non-graphical data requirements. At the time of modelling an element, the designer needs to know the structure of its non-graphical data for the as-built model, even during the preliminary design phase. If it is correctly structured, then the data can later easily be added, but without structure, this element needs to be re-modelled later.

Problem L2
In the BIM requirements, there were some unnecessary requirements that were not followed.

In the client's BIM requirements, there were some unnecessary requirements that were not followed because these were not feasible. For example, there was a requirement that the as-built data for a section in the model needed to be updated within 4 weeks after the construction works on this respective part have been completed. This should have been applied to non-graphical data as well but mostly it was not feasible to update the non-graphical data parallel to construction works. Instead, it was done in larger batches, as often the design team was not available immediately at the request of the general contractor. Another unnecessary requirement was the requirement to link the files of user manuals and product information sheets to the BI Model. Instead it was more feasible to link the folders that contain these files. It was easier for the general contractor and more sustainable for the owner during O&M – in case those files are updated in the future, there is no need to change the link to the folder in the model as the folder stays unchanged, while the file name may not.

Problem L3
The client had included some of the BIM requirements that needed negotiations or reconsiderations.

When the general contractor received BIM requirements for the as-built model, there were some requirements that had to be manually entered, were technically difficult to execute, the machine-readability of a non-graphical data attribute was in question or just timewise or workload wise some non-graphical data was unfeasible. Then, the general contractor turned to the client to determine whether these requirements were in fact necessary. Although there were only some requirements that the client agreed to remove, these negotiations needed time and the decision to keep those other problematic non-graphical data requirements increased modelling workload and costs.

Problem L4
As the general contractor entered the project and the non-graphical data had to be redone to the general contractor's BIM requirements, there were many difficult negotiations.

When the general contractor joined the project, they made a contract with the design firm and one part of the contract was the general contractor's BIM requirements. Most of the non-graphical data had to be added because before the general contractor, there was less non-graphical data in the model. The design team was supposed to model it in the original software which is expensive. Therefore, there were many difficult negotiations about the contract terms between the general contractor and the design team because none of them wanted to cover the costs of remodelling.

Problem L5
Every client uses different BIM requirements, including non-graphical data requirements.

In the beginning of the project, the client came with BIM requirements. Designers and the general contractor needed to spend time to get familiar with requirements, designers had to configure their modelling softwares to be able to add required non-graphical data. There were negotiations about the feasibility of some requirements and some of requirements needed clarification. All this took a considerable amount of time and extra work. This problem had occurred in each project where BIM had been implemented according to the general contractor and the designer and they see it as one of the biggest problems in the Estonian construction industry. What is more, the client admitted that developing their own requirements from the scratch was difficult and took a long time, so this verifies the lack of and need for standard BIM requirements that was identified in the literature review.

4.3. Proposal of solution directions

Solution directions (SD) to problems are provided in this chapter. There are 5 solution directions provided. These are presented in Table 7. These solution directions are broad and have not been tested whether these in fact making the process of adding non-graphical data more efficient. These have been proposed by interviewees and the thesis author.

Table 7. Solution directions for identified problems.

Solution direction	Problem that could be solved with respective solution direction
SD1 Educated and thorough development process of non-graphical BIM data requirements which is completed before the project execution	Problem T5. The non-graphical data that was edited/added in the IFC-format will be prone to interoperability problems in case there are future model modifications or re-modelling.
	Problem M4. The client's requirements development process was slow compared to the whole project completion time.
	Problem L1. Changes in BIM requirements made a large extent of already modelled non-graphical data incorrect according to new requirements and therefore the model needed restructuring.
	Problem L2. In the BIM requirements, there were some unnecessary requirements that were not followed.
	Problem L3. The client had included some of the BIM requirements that needed negotiations or reconsiderations.
	Problem L4. As the general contractor entered the project and the non-graphical data had to be redone to the general contractor's BIM requirements, there were many difficult negotiations.
SD2 Need to develop Estonian non-graphical BIM data requirements standard	Problem L5. Every client uses different BIM requirements, including non-graphical data requirements.
SD3 Need to develop automated technological solutions to discard manual processes in the non-graphical data modelling	Problem T1. The software that the design team used, needed manual creation of attribute fields in a large extent for model elements.
	Problem T2. The design team used a software that needed manual adding of non-graphical data which is prone for mistakes.
	Problem M2. Before the handover, there were disagreements between project parties regarding the cost of manual re-modelling of incomplete/incorrect data.
SD4 Clients need to have their Operations and Maintenance software selected before defining BI Model data requirements	Problem T3. The as-built model's compatibility and machine-readability in a maintenance software was not assured for the client before the handover.
	Problem T4. It was not clear for the general contractor how to make the non-graphical data machine-readable in the BI Model.
SD5 Need to educate industry actors on BIM by means of discussions panels, courses, educational material, and standards	Problem M3. The client did not give exact guidance on solution directions for problems if these occurred.
	Problem E1. Some modelling efforts by the BIM subcontractor were faulty and had to be double-checked by the general contractor.

Solution directions are now further elaborated, and the interviewees' comments and opinions are provided together with solution directions.

SD1 Educated and thorough development process of non-graphical BIM data requirements which is completed before the project execution

Clients should define their BIM requirements in the beginning of the project and not change those during the project. If changes are needed, these should be minor changes that do not need the whole model to be restructured. This would avoid the need to restructure in a large extent and then all minor changes can be done in the original software.

This is a solution where the client's opinion differed with the opinions of the general contractor and the designer. The client argued that generally the whole timeframe of a project is long and for them it is not possible to work out BIM requirements in a detailed way in the beginning and leave everything unchanged, especially when it is their first project with BIM implementation. When they see something problematic, they would like to make changes immediately so they would get a better as-built model. Here, the designer and the general contractor had a different opinion. They thought that in one project, requirements should stay the same and changes should be implemented in next projects. On the other hand, they agreed to changes if the client is compensating those. The

client needs to understand the consequences of their decisions and if they accept the costs that come as a consequence, designers and the general contractor are willing to re-model because they want to offer the best end product as well – it is just impossible to do it for free if the change is significant.

Before the client decides which BIM requirements they are going to use, they need to consult with their facility managers whether all the requirements are necessary. The client should only demand essential information because all the unnecessary non-graphical data is an additional cost for them.

During the project, all project parties should meet to discuss BIM requirements so that the designer and the general contractor could give their feedback on BIM requirements. If there are any requirements, that are not feasible, these should be removed. It creates confusion when there are requirements that are not exactly followed and are still included in the BIM requirements. This information needs to reach all parties and therefore the best way to do it is to have a discussion before the modelling process. By removing the unnecessary requirements, the general contractor and designers can be assured that everything is needed and there is no need for discussion later into the project.

However, the general contractor argued that there is a big limitation to this solution of having a discussion meeting about BIM requirements. In the Estonian construction projects, it is common that the general contractor for the works is procured after the detailed design has been worked out, so most of the BIM process has been completed already. The general contractor is not able to give their input in the beginning, and once they have the possibility to give input, any major change proposals need extensive re-modelling which is expensive and therefore changes are probably not implemented.

What is more, the client argued that already they give their best when assuring that their requirements are in fact necessary. In their opinion, the designer and the general contractor try to negotiate the BIM requirements to make their modelling process easier for themselves. Then again, the general contractor argued that they are just giving their own experience from other projects to help the client not make mistakes that others made and to provide the best BIM expertise they can offer.

Another direction of BIM requirements development on which the interviewees disagreed on, was the amount of non-graphical data that should be required in design phases. According to the designer, detailed non-graphical data should not be added before construction phases, as there are construction working design changes anyway, so the previously entered data is re-modelled. The designer does not see a point in modelling this data early. On the other hand, the general contractor needs that non-graphical data for construction processes and therefore they want to see as much data entered in the BI model as possible before the construction phase. This dispute puts the pressure on the client, and they will be the ones deciding in future whether most data is modelled before or during the construction phase, but the client argued that their main interest is the as-built model and they do not have an opinion on non-graphical data in the construction phase.

SD2 Need to develop Estonian non-graphical BIM data requirements standard

There is a need to work out Estonian BIM requirements standard. Many countries are already moving in that direction. This removes the need to get familiar with new requirements in every project.

The standard could be developed with widely needed non-graphical data and this makes it universal to use. The standard does not have to be used in every project exactly as it is, but it could serve as a basis for project BIM requirements. That means that mostly it stays the same, only some attributes are added or removed based on the exact needs of a specific client. The general contractor argued that most of the clients in the Estonian market are not so large that they need their own specific BIM requirements. Based on the general contractor's experience, clients' demands coincide generally.

BIM standard should be made in a way that the amount of manually added non-graphical data is as little as possible. Estonian market-based BIM standard should be implemented to all the softwares. That means that softwares would have the Estonian market localisation and softwares are able to automatically add most of the data fields to elements.

All the project parties would benefit from the BIM standard and all the interviewees agreed that the standard would greatly contribute towards better BIM implementation. When the standard is developed, the clients should have the biggest say in developing the standard, because if the non-graphical data requirements do not suffice their demands, the standard would be not be used as much as expected.

SD3 Need to develop automated technological solutions to discard manual processes in the non-graphical data modelling

Certainly, there is room for improvement in terms of technological possibilities in the process of adding non-graphical data. There is a need for more automation in the process of adding non-graphical data. For example, a software needs to be developed which based on project-specific requirements automatically checks whether all the non-graphical data has been added correctly. This would significantly decrease workload and costs could be lowered for all project parties. However, incomplete/incorrect data still needs to be added manually which is difficult to make more efficient. According to one of the interviewees, Norway has already developed such a checking software and there is a need for this in the Estonian market too, but a requirement for such a software is to have an Estonian BIM standard.

Additionally, softwares should be more able to automatically generate non-graphical data fields and fill those with non-graphical data. Now, this is very manual, and the designer, that was interviewed, added that it would much more increase their willingness to implement BIM. More automated process lets them focus more on the engineering side of designing which is essentially their job.

SD4 Clients need to have their Operations and Maintenance software selected before defining BI Model data requirements

The client should have a maintenance software ready already at the time when they start designing BIM requirements. The output of BIM is essentially the input for maintenance software. There are several benefits to having a maintenance software ready. For example, it is known which attributes can be entered as which data types. The model can be tested in the beginning to see which data types in different data fields are experiencing problems regarding machine-readability. Then the model can be adjusted and based on this the whole modelling process can avoid a need to re-model later. Another example is that the model can be tested and evaluated midway into the process of BIM. The client can validate and check the non-graphical data in the model and if they are not happy with the data quality, they can intervene.

SD5 Need to educate industry actors on BIM by means of discussions panels, courses, educational material, and standards

The last solution direction takes effect once BIM is more implemented and BIM expertise among industry actors increases. Currently, BIM is a field which is developing rapidly and with this comes experience. This is not necessarily easy to accelerate, because according to interviewees their knowledge comes only with executed projects, but there are ways how industry actors could share knowledge.

Most importantly, clients need educating on BIM. Clients are the actors with the most influence in construction industry. The client in this project was not familiar with BIM but they learnt throughout the process. Now, they are one of the most educated large-scale clients in Estonia. To avoid problems in future, other clients should be educated before the project, not during the project. If the clients are educated, they know better what to ask for and in case there are any issues, they can give guidance because they are the only ones who know exactly how they are going to use the as-built model in the future and they are in the best position to give guidance.

The same goes for designers, general contractors, and BIM solutions contractors as well. They are responsible for the technical aspects of non-graphical data modelling and therefore need to learn how to make it as efficient as possible.

Ways of educating industry actors are discussion panels, courses, educational material, and even an Estonian market-based BIM standard could in some way educate actors. In addition, the standard decreases the need to educate because all project parties would work according to the standard and the coordinators necessarily do not need to be well-educated an responding to all the problems, because the standard could give guidelines to frequently occurring issues.

The designer argued that client education is one of the most important solution directions for BIM, because if the clients are educated, they know what to ask for in terms of non-graphical data. BIM is attractive to clients and if they are educated, they get a good model fitted to their demands and future use in O&M.

On the other hand, the client argued that they must do a lot of educating for the general contractor and designers as well. In projects where they have procured a less-experienced designers and general contractors, they need to go over the same problems again, but a standard or experience sharing by means of panels could discard this need.

Explanation to unsolved problems

There were two problems that were not linked to solution directions:

- Problem M1. The client was unaware of the as built model status and the non-graphical data quality during the modelling process.
- Problem M5. Non-graphical data in the BI Model was outdated at times.

These problems are not necessarily possible to be solved with presented solution directions. For those, the process of adding non-graphical data needs to be well-coordinated. It was not given as a separate solution direction because the BIM coordinator already did their best to have a well-coordinated process. The reason that these happened was that many parties were to blame for these problems and the coordination cannot be perfectly executed unless all parties collaborate and give their best.

5. Discussion

In this research, the project that was studied might seem very problematic, as 17 problems were found in the process of adding non-graphical data. However, all the people that were interviewed assessed the process of adding non-graphical data as overall positive in their reflection. The client was positive and was willing to look for middle ground, and because of that interviewees considered this project as a great learning environment.

One limitation of the study is its predominating perception of the client causing many problems. It should be emphasised that the client was not directly involved in the process of adding non-graphical data and therefore it could have been easy for interviewees to criticise the client. For the client it is difficult to defend their position because they were not involved in the process of adding non-graphical data, especially in the technical side of it. So, future research could study projects where the client is more involved in the process of modelling non-graphical data.

Prior research stated that there are problems with the process of adding non-graphical data to BIM such as clients struggling to define non-graphical data requirements; some of the modelling efforts being duplicated by both the designers and general contractors; facility managers receiving maintenance information in various formats. From these three, the latter was not identified as a problem in this case, mostly because of structured BIM requirements with clear output definition. However, the second problem has previously been stated very vaguely in literature. If to view the modelling efforts more broadly, there are more problems in the technical process of modelling non-graphical data than just duplicated modelling efforts.

Additionally, this research improved a BIM implementation assessment framework by Chien, Huang & Wu (2014) so it would fit the modelling process of non-graphical BIM data. Future research could study the fitting of this framework for non-graphical data modelling assessment.

In terms of the thesis methodology, framework for categorising problems could have been defined earlier. The framework was chosen in hindsight and that may have changed the identification of problems. The most fitting framework was chosen according to the problems, but this is not completely objective. If the framework would have been chosen earlier, the questions for interviews could have been prepared better as the framework's theory might be different from the thesis author's idea of what a problem is. However, as there is no exact framework for assessing non-graphical data adding problems, then this was done in hindsight.

As for the interviews, it was observed that not all facts were remembered about the process from the early stages. Therefore, some problems from earlier stages might have been left out. The project lasted for 5 years and not all interviewees have been involved in the project right from the start until the end. Additionally, the thesis is completed some weeks before the handover of the building, so last problems in the project might be left out as well.

One of the problems in this project was the fact that the client decided to change their BIM requirements. It did create many other problems in the process of adding non-graphical data, but all project parties admitted that the client did the right thing when changing the requirements, as now they receive much more beneficial as-built model for their O&M phases. If they would not have made those changes, their model would have been with a lower quality and there might be completely different problems in the process of adding non-graphical data.

6. Recommendations

Future research directions could be the following:

- Solution directions should be worked to detailed guidelines
- Efficiency assessment of solution directions
- Study next projects from the Port of Tallinn where they use the same requirements

In future research, the solution directions should be worked into more detailed options. Currently, solution directions are very broad and do not give exact step-by-step guidelines on how to improve the process of adding non-graphical data. With problems clearly defined and solution directions given, coming up with solutions could be interesting scientific research.

Another topic that would need scientific research is the assessment of efficiency for these solution directions. Currently, the efficiency of solutions could not be assessed in project environments. These solutions should be tried in a project environment to see whether these had any benefits. As project lifecycles are long and to draw conclusions from projects, these solutions should be implemented immediately, so the results can be seen in few years.

In terms of this project, another interesting topic of research would be to assess the process of adding non-graphical data in other Port of Tallinn projects. They are using the same BIM requirements that they developed during this project in other projects already, namely for construction of a cruise ship terminal and a parking facility. The client is the same, the BIM requirements are the same, but new general contractors are carrying out works and it would be great to study the process in an environment where the client is educated and experienced now and tries to implement the same BIM requirements. In theory, it should be much more efficient process but to see whether it is in fact true, there is need for research.

To conclude, in general, non-graphical data is part of BIM which has not received enough scientific attention. If more scientific research is done about non-graphical data, better solutions can be developed for the implementation of non-graphical data. As it is such a significant part of BIM, there is much room for improvement.

7. Conclusions

In this research, the aim was to identify problems in the process of adding non-graphical data to BI Models and propose possible solution directions to these problems. This study is a case study about the reconstruction project of D passenger terminal in the Port of Tallinn. As part of the case study, the process of adding non-graphical data in this specific project was reconstructed.

This thesis was done mainly by interviewing representatives of the client, the designers, and the general contractors. Additionally, some insight was gained from the project documentation and conclusions from a public webinar where project parties reflected on the process of BIM implementation in this project.

There was a total of 16 problems identified in the process of adding non-graphical data. These problems were categorised to 4 different groups according to a framework by Chien, Huang & Wu (2014). These categories were Technical problems; Management problems; Environmental problems; and Legal problems. There were 5, 5, 1 and 5 problems identified in these categories, respectively.

Although the category of legal problems did not have the most problems out of all the categories, it had the most impactful problem, which caused many other problems. According to the designer and the general contractor, the most impactful problem in this project was the fact that the client changed the BIM requirements three times in this project. Due to this, significant amount of non-graphical data in the model had to be restructured. This brought many problems because most of the restructuring was manual, time-consuming and therefore costly.

Another impactful problem was the client's lack of experience in the field of BIM. This was partly the reason why they changed BIM requirements, as throughout the project they became more experienced and more educated about BIM and with better knowledge they asked for a better-quality as-built model. However, during the project, in case there were issues, client was not able to give guidance, and the general contractor and the designer had to rely on their previous experience on other projects. What is more, the client cannot test the as-built model and its non-graphical data before the handover, meaning that the machine-readability and compatibility of the non-graphical data in the as-built model is still in question before the handover.

In the thesis, there are five solution directions provided that could improve the process of adding non-graphical data.

Clients should define their BIM requirements in the beginning of the project and not change those during the project. This would avoid the need to restructure in a large extent and then all minor changes can be done in the original software. Before the client decides which BIM requirements they are going to use, they need to consult with their facility managers whether all the requirements are necessary. The client should only demand essential information because all the unnecessary non-graphical data is an additional cost for them. This would contribute to better development of BIM requirements and a smoother process of adding non-graphical data.

One way of better development of BIM requirements would be the Estonian market based BIM requirements. This would set the industry standard that all the actors in the industry would be familiar with; which would have feasible and necessary non-graphical data content; and which would give guidelines on the process of adding non-graphical data. Additionally, the standard could improve other aspects of BIM, not only non-graphical data related aspects.

There is a need for better softwares and technological solutions to improve the process by means of automation. This would decrease modellers' workload and improve designers' willingness to model non-graphical data changes and improve their attitude towards non-graphical data, as currently they focus too much time on the non-graphical data, not on designing engineering solutions which is essentially their job.

Lastly, industry actors need education about BIM. The client in this specific project learnt during the process and became one of the most educated clients in the Estonian construction sector but their learning process came through problems and reacting to problems. If other clients could avoid these problems and already learn about BIM implementation before a project, the process of adding non-graphical data could be much smoother. The same goes for the general contractor and the designer. There should be events where experience and knowledge are shared between industry actors. The clients are the most important actors in the construction industry, and they have the responsibility to implement BIM. If industry actors are well-educated, BIM and its use processes will see increase in quality in next decades.

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9. Appendices

9.1. Appendix A. Interviews

Interview A. 20 April 2020 via MS Teams.

Interviewees: two people from the general contractor

Questions:

How does exactly non-graphical data adding process work?

Why is non-graphical data added with Excel templates? Why is it not in the model already?

What BIM requirements were in the construction procurement?

In which stage were the COBIM 2012 requirements as BIM requirements?

When and how did you develop your own BIM requirements and in which projects do you use those?

When did you first hear about the client having an idea to make their own BIM requirements?

How did the fact that they were developing their own BIM requirements impact your regular process of adding non-graphical data?

When the client was developing their own BIM requirements, how much feedback did they ask from you?

When the client finalised their BIM requirements, what other alternatives did you have to restructure the model?

Is the BIM subcontractor the only contractor that provides this service to restructure the model?

When did the BIM subcontractor get involved in the process?

Did you hand over a separate as-built BI Model after the completion of the construction works of stage 1?

Does the rule of keeping data in the model up to date with a delay of not more than 4 weeks apply to non-graphical data as well?

How do you keep records about the changes in non-graphical data if you model those changes in groups?

How much is the client involved in the process of adding non-graphical data?

How much are the construction subcontractors involved in the process of adding non-graphical data?

What are the last steps you take before handing over the model to the client?

Do you stay responsible for the model after the handover?

Has the model been tested in a maintenance software?

Interview B. 28 April 2020 via MS Teams.

Interviewee: a design engineer

Questions:

What is your role in the D terminal project?

How many people were in the process from your engineering design firm?

What are the first steps for designers after the procurement has been won?

In your company, do you have your own BIM requirements that you use in case the client provides none?

Why there was a new contract made in 2017?

When did you first hear about the fact that the BIM requirements will change?

If you would know before about BIM requirements changes, would this help you?

For this, do you need the exact as-built model structure or just the client mentioning the fact that requirements change is enough?

Do BIM requirements changes happen often in projects?

What was your stance toward the change of BIM requirements?

What were the main problems in the process of adding non-graphical data?

What problems have you experienced with communication?

Have there been any problems with coordination of the process?

What is your opinion about the BIM subcontractor in this project?

What problems have you experienced in your planning?

What technological or software problems have you experienced?

What strengths have been in the project?

What have you learned the most in this project?

How satisfied are you with other project parties?

Interview C. 5 May 2020 via MS Teams

Interviewee: representative of the general contractor

Questions:

What were the main problems in the process of adding non-graphical data?

What are the main problems in adding the product-specific non-graphical data?

Do BIM requirements changes happen often in projects?

Where did you get the motivation to be positive about BIM requirements changes?

What were the attributes in non-graphical data that you considered unnecessary?

What was your stance toward the change of BIM requirements taking 6 months?

What requirements are there in the BIM requirements that are unnecessary or unfeasible?

What problems have you experienced with communication?

How has the communication been with the client?

What is your opinion about the BIM subcontractor in this project?

Why did the BIM subcontractor make mistakes?

Have there been any problems with coordination of the process?

What problems have you experienced in your planning?

What technological or software problems have you experienced?

What is your opinion on the development of the Estonian BIM standard?

What strengths have been in the project?

What have you learned the most in this project?

How satisfied are you with other project parties?

Why did you not hand over a separate as-built model after the completion of stage 1?

Interview D. 12 May 2020 via MS Teams

Interviewees: two people representing the client

Questions:

What is your role in the D terminal project?

When did you start with the project?

What was your experience with BIM before the project?

Have you had BIM requirements in other Port of Tallinn projects?

How did you get to the point of implementation of BIM?

How did you select BIM requirements for procurements and was it difficult to choose?

Why did you decide to develop your own BIM requirements?

How did the process of developing BIM requirements go?

Who did you involve to the development process?

Were you aware of the problems that BIM requirements changes will bring?

How involved have you been with the process of adding non-graphical data?

Do you wish to be more involved?

What problems have you encountered with communication?

How do you plan to use the non-graphical data in the future?

Do you already have the maintenance software that you are going to use for this as-built model?

What have you learned from other projects where you use your BIM requirements?

What have you learnt the most in this project?

How satisfied are you with other project parties?