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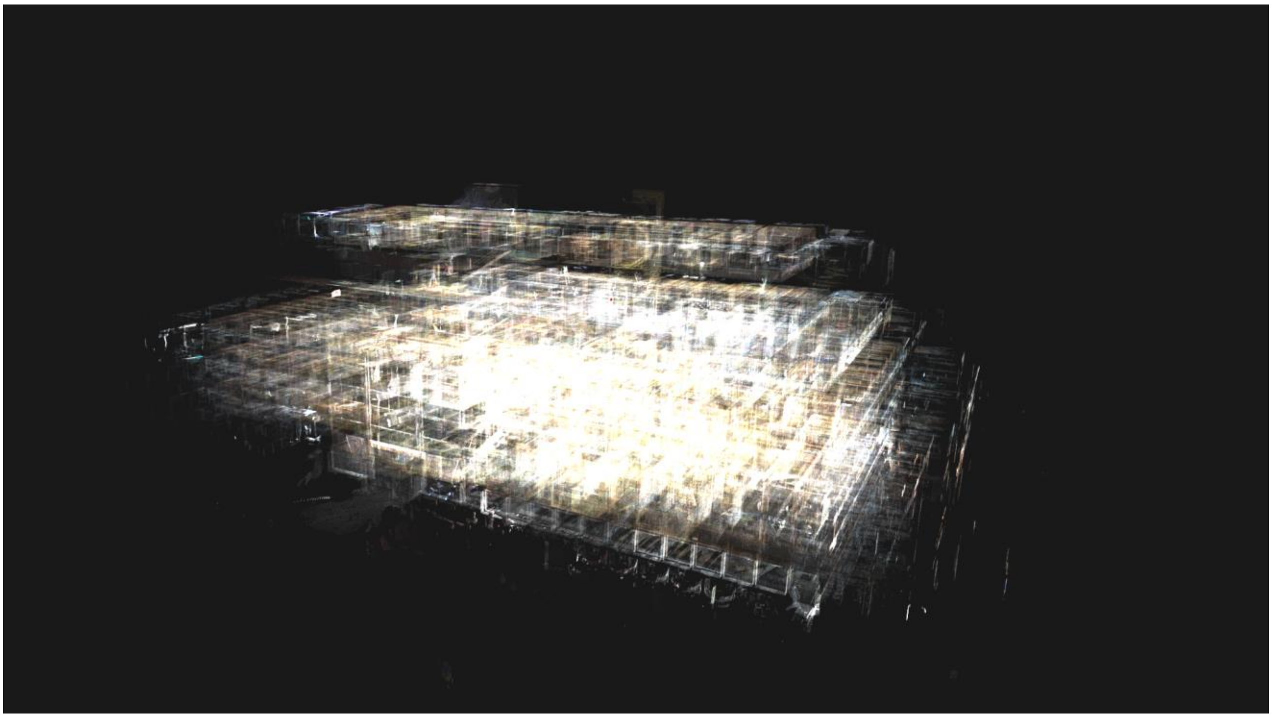

Validating construction project data for a Digital Twin

The process of providing as-built information in a facility's Digital Twin.

Master's thesis in the Master's Program of Design and Construction Project Management

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A point-cloud of a construction project. (Zynka Group, 2021)
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ABSTRACT

The facility management and operational stakeholders of a building are today widely relying on information provided from the design phase of the building project. To ensure that more relevant and accurate information is generated, the industry has embraced the Digital Twin. The Digital Twin's purpose is to mirror the geometry of the physical asset in a digital manner while also connecting it with non-geometrical information, which provides knowledge and insights.

The connection between geometrical and non-geometrical information is carried out by utilizing a validation process made in several steps. The process also varies depending on what information is being handled. To gather information from the as-built environment a laser scanning is made to create a point-cloud acting as a geometrical representation of the physical asset. This point-cloud is later connected with non-geometrical information through the process of validation. The process is carried out partly by subcontractors which connects the physically installed objects, scanned into the Digital Twin, to non-geometric information such as product data.

The validation is summarized to be a helpful way of structuring information and connecting it to physical positions. However, it has been concluded that what information that is deemed relevant heavily varies between projects and who is going to receive the information. It is therefore suggested to make an early mapping of involved stakeholders interest in what information that should be provided in the Digital Twin.

Key words:

Digital Twin, As-built, Facility Management, Point-cloud, Building Lifecycle, AECOO

Contents

PREFACE

This Master's thesis was conducted at the Department of Architecture and Civil Engineering at Division of Construction Management during the spring semester 2021 at Chalmers University of Technology, Sweden. The thesis was conducted in such way to combine theoretical knowledge and practical knowledge gained from cases and interviews in the industry. This would not have been possible without the help and support from the following people:

- Mattias Roupé: Supervisor and Examiner at Chalmers
- Daniel Månsson: Supervisor at Zynka BIM AB
- Nils Hellberg: Project coordinator at Zynka BIM AB
- Simon Ståhlkrantz: Colleague at Chalmers
- The Respondents
- Anna Larsson: Opponents at Chalmers
- Rebecca Engvall: Opponents at Chalmers

We would therefore address our gratitude towards these people and once again thank them for their help and insights.

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Daniel Páldeák

Anton Wikhede

NOTATIONS

AECOO – Architect, Engineer, Construction, Owner & Operation

BIM – Building Information Modeling

BLC – Building Life Cycle

FM – Facility Management

IFC – Industry Foundation Classes

LOD – Level of detail

O&M – Operations and Maintenance

POI – Point of Interest

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1 Introduction

1.1 Background

The growing interest of a digital shift in Architecture, Engineering and Construction (AEC) industry play an important role in addressing the issue of ineffective processes (Volk et al., 2014). The shift has gradually moved from usage of digital visualization to optimizing specific workflows that focus on effective capture of information, analyzing of information and dissemination of information (Hardin & McCool, 2015). The growing interest of information have passed over to Facility Management (FM), where the interest regarding information and knowledge gathered from design through the process of construction is applied to Operation and Maintenance (O&M) stages of the buildings lifecycle (Becerik-Gerber et al., 2012).

The increasing interest of information throughout the processes in AEC and FM shed light on the concerns regarding work between stakeholders in the industry (Bosch-Sijtsema & Henriksson, 2014). The issues regarding communication and information-sharing are often associated with a description of the industry as being fragmented (Becerik-Gerber et al., 2012; Bosch-Sijtsema & Henriksson, 2014; Lantmäteriet, 2018; Rasmussen et al., 2019). The fragmentation of AEC originates from numerous different stakeholders that work together during different processes and gathered different information regarding the process (Rasmussen et al., 2019). In addition to this the level of digital understanding, implementation of information handling and lack of common goals is vastly different between the stakeholders involved in the process.

A digital flow of information throughout the whole building process, with a full integration of all involved parts is according to Bosch-Sijtsema, van Raalte, and Carlstedt (2020) a goal to strive for which could facilitate knowledge management through the whole building process, from design to FM. A potential solution is Building Information Modelling (BIM), which through the digitalizing of project information in a structured format can act as a catalyst for knowledge management within projects and between different processes (BIM Alliance, 2016; Bosch-Sijtsema et al., 2020; Whyte, Stasis, et al., 2016). The primary goal is according to Bosch-Sijtsema et al. (2020) to have the correct information accessible at the right time for the right stakeholder for the sake of facilitating successful projects.

A concept which can facilitate the information management through the project lifecycle is the Digital Twin (DT) which collects data and project information, such as BIM, and creates a virtual representation (Jones et al., 2020). By not only utilizing information from design, but also gathering information of how the asset actually was build the DT will help future processes of i.e. FM (Çıdık et al., 2017). This can be done through the method of laser scanning the build environment, creating a Point-Cloud made up of several million points, that visualizes the asset (Klein et al., 2012).

To enrich the point cloud, thus also the DT, one can connect specific points in the point cloud, that represents objects or spaces of interest, to non-geometrical information such as product datasheets or service information. This should be done via a validation process, where someone affirms the objects spatial position as well as connecting correct information to correct object. This thesis is set up to examine current process of validation as well as discussing how it can be improved.

1.2 Aim

This thesis aims to describe and evaluate the impact of a multidisciplinary process validating the project information that is being shared between design, production and facility management and explore how this process would take form with a point-cloud based approach. The main point of the process is to make correct information accessible during the operational stage of the Building Life Cycle which derives from the potential user of information in addition to the importance of having accurate information at the right time.

1.3 Research questions

In the light of the previously stated problematization the following research questions have been formulated:

- Which information is determined to be relevant for validation in a construction project?
- Who would be responsible for the validation and how would it be carried out?
- What impact would a validation of information have for involved stakeholders?

1.4 Limitations

The study is mainly focused on the Swedish Architect, Engineer, Construction, Owner & Operation (AECOO) industry, where the center of attention will be commercial real estate projects and its stakeholders, thus excluding other projects within the sector such as large-scale infrastructure projects or housing projects. It is neither the task of this thesis to examine the maintenance of the project information during the operational stage, nor to rank what type of information, which is considered relevant in the context, but rather to explore the potential process leading to verified and relevant information being delivered.

2 Method

2.1 Research design

One of the first steps for a study to take is to define what type of research that the thesis will conduct. There are three main ways of choosing where to start; either by conducting an *exploratory, deductive* or *hypothesis formulating research* (Patel & Davidson, 2003). They further explain that it is not exclusive to only choosing one of these methods, rather on the contrary they explain that in bigger studies two or even all three methods are used throughout the study (Patel & Davidson, 2003). This thesis starts with an exploratory research to facilitate knowledge within the subject which would act as a foundation when problem formulation and aim of the thesis were being formulated. Information was gathered regarding stakeholders of AECOO and what type of information that they use and transfer to the next phase to fill information gaps. This approach aligns with Patel and Davidsons (2003) described aim of an exploratory method, to fill knowledge gaps within a subject and to gather as much information as possible about the subject matter.

When the needs of basic information were met and the problem formulating, and aim was finished another stage of searching for information began in the form of a deduction methodology. The study now needed more information regarding how information is used today and what has been the change the last years within the industry. As well as analyzing what the reasons are for change and what are the barriers for the change. This falls in line with Patel and Davidsons (2003) explanation of a descriptive methodology, that states that it is used when a basic understanding of information already exist and the subject is analyzed in both present and past cases. As well as the research mainly focuses on a few aspects at a time or the relationship between a few aspects (Patel & Davidson, 2003).

The thesis then needed to choose what kind of research strategy that would be carried out through the study. A qualitative method was used for its practical usage when most information is gained in the form of words from papers, company reports and interviews. According to Bryman (2012) and Patel & Davidson (2003) qualitative research often works with text formatted data and is based on the interpretation of data from different sources such as articles, interviews or other sources. Multiple rounds of interpretation and addition of new information to narrow the scope of the project are made to strengthen the final findings (Bryman, 2012). The allowance of analysis being made simultaneously with the gathering of information enables exploration of new ideas and increased quality in unison when the interviews were carried out (Patel & Davidson, 2003).

Information gathering is a process that follow along the work of study and were divided into multiple different work schedules and sorts. The gathering of information was done in three steps: literature review, case study and interview study as described in Figure 1. Followed by compilation of the gathered information as well as a discussion and conclusion.

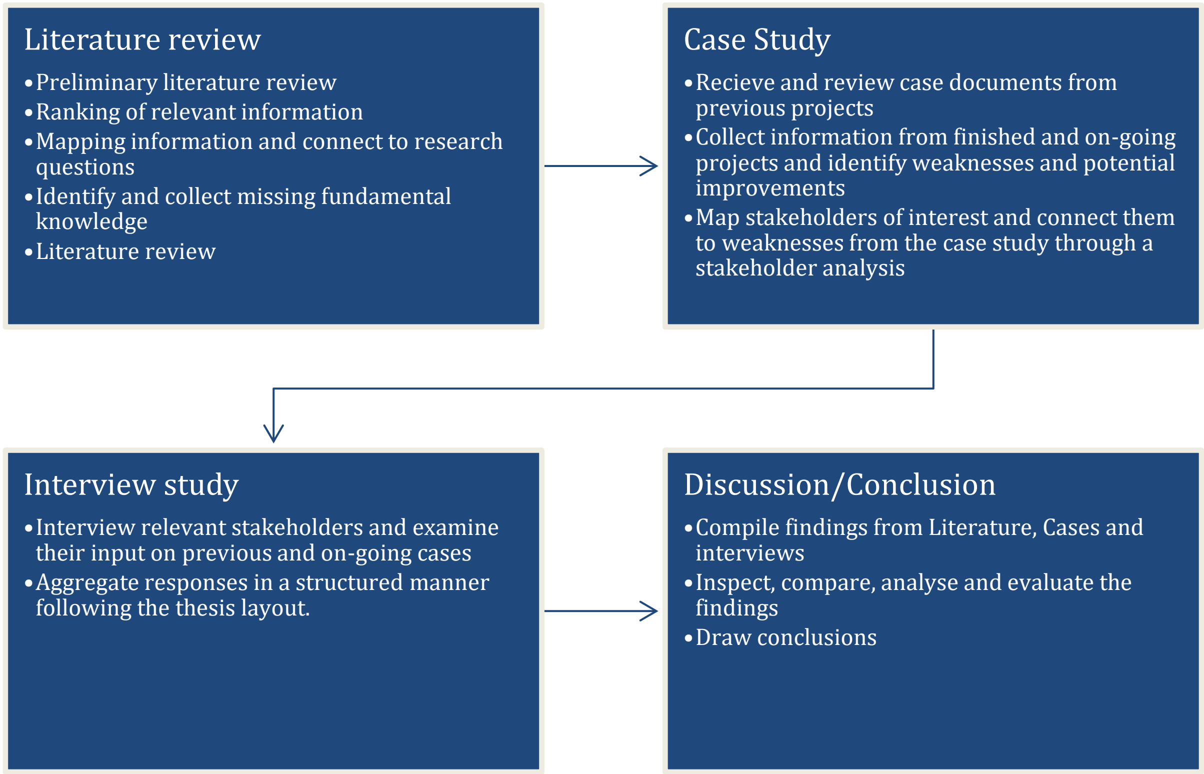

Figure 1. The process model of the thesis.

The first information that was gathered was basic information to create a foundation for the introduction part of the thesis and helped to formulate the questions that the thesis set out to answer. This information gathering was done by searching for literature and discussions with the thesis supervisor and contact company Zynka BIM AB.

The final formulation of the questions was made in discussion with both the contact company and the thesis supervisor. After question formulation and discussion about the subject, the thesis focused on finding information fit for the theoretical framework. This information aimed to function as the backbone of the thesis and facilitates the reader with the crucial information to understand the context and result of the study. Further, how and what type of information was gathered will be presented in the next header 3 Literature review.

The next step for the thesis was to gather case information. This was collected from the consultant company Zynka's previous and ongoing projects to collect information regarding how the investigated process was carried out in practice.

Final step for information gathering was to make 8 interviews with the stakeholders that was of interest for the specific process of information validation. The interviews in combination with the case information work as the thesis primary information source while the different literature segments functions as secondary information to describe the context of the study. The result from the interviews is presented in an aggregated way that is described under header 5 Interview Study.

2.2 Information Gathering

This section aims to describe the three methods that were used to collect information: literature study, case study and interview study. The purpose of combining these methods is for the different results to complement each other, thus creating a comprehensive view of the problem.

2.2.1 Literature Study

The search for literature was divided into three stages: finding background information (to give the thesis a foundation), search for theory (to give the reader context of the area) and compile a literature review (regarding information that was found in case studies).

The first search was mainly done using Chalmers library function called ODR that store student work that are both from bachelor and master thesis written at the university. The search words were “BIM”, “facility management” in combination with theses purposed by the supervisor where he had supervised before, focusing on the digital change of AECOO. From these theses the concept of snowball sampling was used to read the sources that others have used before to find additional sources within the topic. Bryman (2012) describes the snowball sampling as a method to research suggested work based on an initial small sample. The initial start of 6 master theses ended up in 13 number of relevant articles. This method was applied throughout the different stages of information gathering to build up as much knowledge about the subject as possible.

Another round of literature research was conducted to compile the thesis theory, which was aimed to be the theoretical foundation approach of the thesis. The search was made with Google Scholar and Scopus, where the overall applied criteria for studies was set to be published after 2010. The subjects researched were “BIM”, “BIM in FM”, “Validation process in AECOO”, “Barriers for information in FM”, “stages of BIM models”, “Point-Cloud in Construction”, “Image scanning”, “Digital Twin in construction” and “laser scanning”. Since there is not that much of information regarding digital twins in the industry that are concrete in its usage, other technologies regarding information gathering and usage such as Point-Cloud and BIM is in this study categorized as a form of a digital twin and goes in line with the thesis definition.

2.2.2 Case study

The case study was carried out on two different cases. Both cases were chosen to this study since they have or had tried to implement the aspect of validating information digitally in one way or another. Case 1 was an already finished project, where documentation had been made afterwards in coordination between the consultant and the client. The documentations where primarily made to describe and evaluate the project with a focus on innovational subprojects that were carried out, such as the validation process. On top of this, case information from Case 1 also consisted of demonstration of the finished Digital Twin and its functions, which was carried out by the consultant.

Case 2 was an on-going case which had a different approach compared to Case 1 which enabled a different point of view on the Validation process and how it was implemented in the project. The project was not as well-documented as Case 1 and had relied on unwritten communication between consultant and contractor. This implied that main information concerning Case 2 was gathered from the contact company in forms of discussions with the consultants working at the project. The information, gathered in discussions, was regarding how the initial planning and first steps of the case had been carried out.

Based on the information from both cases, a stakeholder analysis was made to identify involved stakeholders' relations to each other and their influence in the outcome of the validation process. This analysis later became the foundation to identify respondents of interest for the interviews.

2.2.3 Stakeholder analysis

In order to know who to interview and why that respondent would be of use for the thesis, a stakeholder analysis was created. All connecting stakeholders to the regarding cases were set up and in boxes on a dashboard. Then four questions were asked regarding each of the stakeholder.

- How would the stakeholder's interest be affected by a validation process?
- How would the stakeholder be able to affect the outcome of the validation?
- How does the stakeholder benefit from a validation?
- What obligations does the stakeholder have towards the validation?

By answering these questions and then also discussing the results with both the thesis supervisor and contact company, three stakeholders were deemed interesting to interview. The stakeholders were contractor, subcontractor and client/facility manager. At first the supplier also seemed interesting, but to keep the thesis inside the scope of the study, as to analyse the validation process and all stakeholders involved. Other types of stakeholders still have a connection in some shape or form, but the study focuses on these four since they are directly linked to the process and the result of the process efficiency.

2.2.4 Interview study

One of the primary sources of data for the thesis were the interviews that were conducted with the stakeholders identified in the stakeholder analysis. The respondents interviewed had a similarity that all of them had been part of a previous projects that implemented a validation process, but not exclusively case 1. There were eight interviews conducted and nine respondents were interviewed. Due to occurring restrictions of the Covid-19 pandemic, all the interviews were held digital, where the interview questions were sent in beforehand to make the respondents think through their answers. The interview information can be seen in Table 1 below that describes the respondent's role, what type of stakeholder they are and detail regarding when and how long the interview was.

Table 1. Specification of participating respondents.

Interview nr	ID	Date	Length	Stakeholder	Role
Interview 1	S1	26/03/2021	40 min	Subcontractor (HVAC)	Project Manager
Interview 2	C1	31/03/2021	45 min	Contractor	Project Manager
Interview 3	FM1	06/04/2021	48 min	Client	2 x Information Manager
Interview 4	FM2	07/04/2021	38 min	Client	Project Manager
Interview 5	C2	12/04/2021	28 min	Contractor	Project Engineer
Interview 6	C3	16/04/2021	47 min	Contractor	Supervisor
Interview 7	C4	19/04/2021	40 min	Contractor	Design Manager
Interview 8	S2	21/04/21	30 min	Subcontractor (Electrician)	Project Manager

The interviews were made to emphasize the respondent's objective and subjective understanding of the validation process as it is today and what they want to change to make it fit their interest better. By doing this with all the stakeholders the study gets a broad oversight of where the interests overlap. Since the respondents came from different companies with different connection to the process the study utilized semi-structured interviews to enable flexibility in the conversation. The approach of a qualitative interview is to have a low structure since this allows the respondents to steer the interview according to their own concerns and agenda. These are highly regarded since they give more information about what the respondents deem to be important (Bryman, 2012; Kvale & Brinkmann, 2015; Patel & Davidson, 2003). To accommodate this type of structure, templates for each stakeholder was created with questions fitting within the scope of the subject to create an outlining frame of the conversation and promote further discussions within the topic. This structure also made the compiling and processing of information from the interviews easier. The interview templates can be found in 9. Attachment 1: Interview guide.

2.3 Disposition

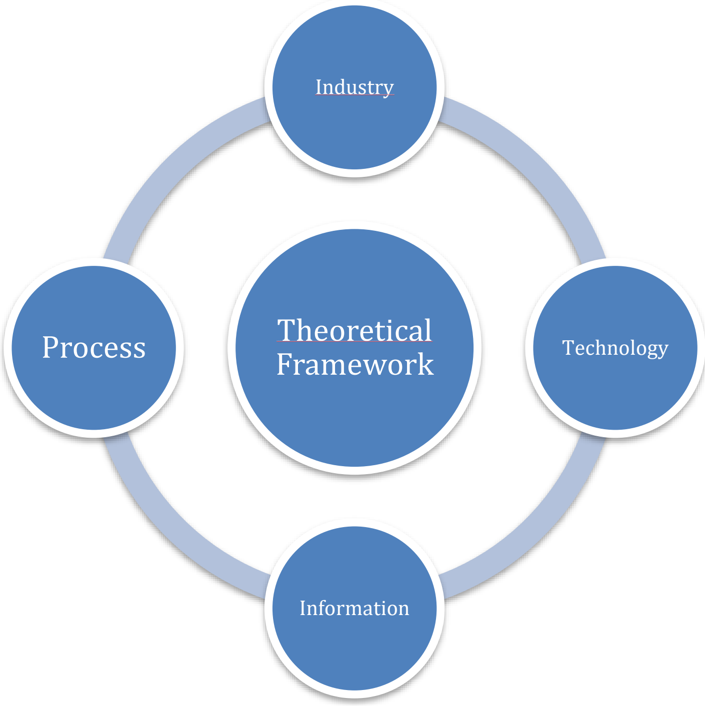

Figure 2. The four sections of the literature review. Authors own creation.

As described in Figure 2 a categorization structure was created to categorize information more easily throughout the studies but also to make it easier for the reader to follow the content of each part of the thesis. Category is divided into four parts Industry, Technology, Information and Process. Industry is categorized as the current state of industry and how all parts of the Building Life Cycle (BLC) connect to the validation process and the needs and barriers that they face to implement new technologies. Technology describes what type of technology that is used in the industry today but also what is aspired to reach and what the benefits and barriers that these technologies face. Information defines the different levels of information needed and how to categorize it, further it also describes the needs and barrier of information that exists in AECOO. Lastly, Process describes the micro processes that is connected to carrying out validation of information. It describes the current state but also future work process and how they function in real cases.

All the interviews that were conducted in the study was recorded to further increase the precision on quotes and information used in 5. Interview Study. Processing of information was made in such way that the contexts of the answers given by respondents were analyzed in regard to the four sections Industry, Technology, Information and Process. The information gathered under each topic was then used as claims that either contrasted each other or strengthen the views of the stakeholders. Quotes were taken from the transcription to further show the respondents claims and perceptions, the method can be seen in Figure 3 below.

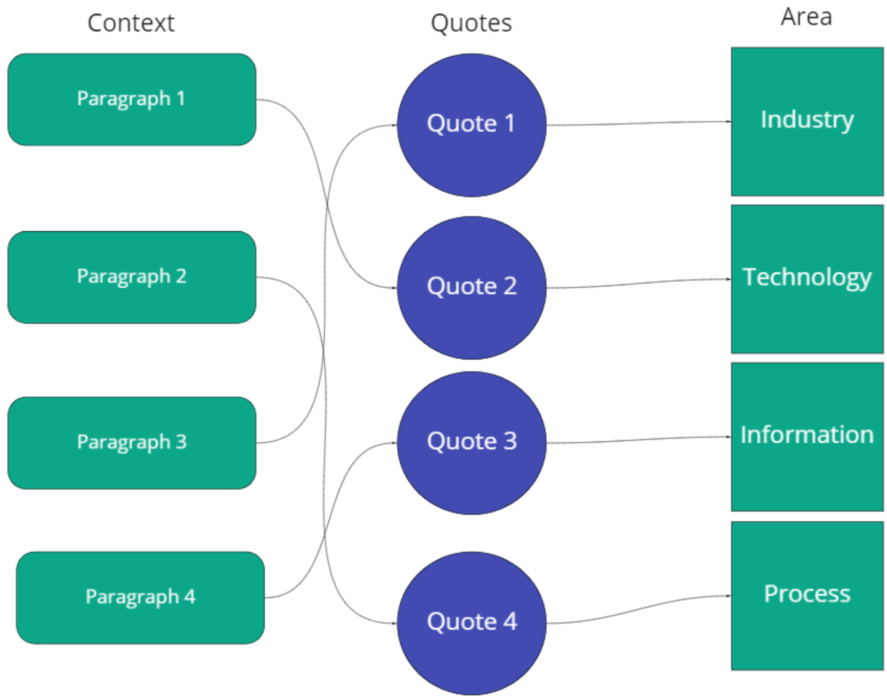

Figure 3 Method of processing interview information. Authors own creation

This categorization system makes it easier to connect the three studies in 6. Discussion. The structure makes it easier to see similarities and differences in subject between the studies and therefore allows the thesis to properly address them in a discussion that leads to material to answer the research questions in 7. Conclusion.

2.4 Research quality

Several methods currently exist for the measurement of the research quality and this thesis focuses on *Trustworthiness.* Bryman (2012) describes trustworthiness as a combination of four criteria Credibility, Transferability, Dependability and Confirmability. Bryman continues to describe that the terms of validity and reliability is hard to address in an qualitative research study and hence why trustworthiness should be used instead (Bryman, 2012).

First criteria is credibility that can be described as usage of good practice when research is conducted and that the understanding of participants answers are confirmed by the participant (Bryman, 2012). To use a good practice when research was carried out, the study used multiple ways of confirming that the results and questions were relevant in the context it was established by asking supervisors and analyzing former research on the subject.

Transferability is the second criteria and Bryman (2012) with the use of Lincoln and Guba (1985) describe it as giving the reader an understanding of the surrounding culture when information was gathered, not so that one can make the same research again, but so one can understand how the outcome was made. The thesis takes this into account and try to define the setting of how information was gathered, what information was given to the respondents before, during and after as well as why certain choices were made. By giving the readers this, they can make up their own mind whether the result is analyzed correctly.

Third criteria for trustworthiness is dependability, Bryman (2012) characterize it by creating an auditing approach throughout the study, by keeping complete records of interviews, notes, different selections, analysis and decisions peers can help with audit the information. The concept of auditing was also applied to the scheduled meetings with Zynka´s representatives and the thesis supervisor every third week to discuss and audit the progress so far and explain why information was analyzed in the way it was. This led to new ways of looking at the information since it allowed different viewpoints to be discussed and therefor new understandings of contexts arose.

Confirmability is the last criteria, and the study can be seen taking this into account when critique is directed towards that the qualitative approach which is based on the authors and other participants interpretation of case information and interviews. This implies that complete objectivity is not possible to reach. However, by allowing the reader to read up on compilation and the processing of information described above, the study shows transparency that the process have preventively acted against being influenced by personal opinions as the main information. Bryman (2012) describes conformability as a way of recognizing that complete objectivity is a fallacy and to express that the study did not overly allow theoretical or personal information that sway the findings of research.

2.5 Ethic

Research into ethics have different takes on how to assure good ethical principals in research. Informed consent is a crucial part of research and principally in interview-based studies. This is addressed by giving the respondents as much information as needed for the respondents to make informed decisions about participation (Bryman, 2012; Kvale & Brinkmann, 2015). The respondents where given information about the aim of the study from the initial contact to show transparency towards their participation. The information was then repeated before the interview started as well as a question if they still wanted to participate, to make sure that informed consent was met. The respondents were also provided the information of how and when the result would be presented. Both Bryman (2012) and Kvale and Brinkmann (2015) describe that invasion of privacy plays a big role in ethical research, since many of us hold privacy dear which is connected to informed consent. The study believe that privacy plays an important role both for respondents but also company information. Therefore, the thesis applied confidentiality regarding these two remarks. Kvale and Brinkmann (2015) describe confidentiality as withholding of information that can be used in such way to identify the respondents. For the thesis to act confidential with details after the interview transcription was made, all the names were anonymized before showing the results. The only information that was kept was date of the interview, length of the interview, respondent's role and which stakeholder the respondent represented which is show under Table 1. Bryman (2012) mention how psychological harm to respondents must be unacceptable, harm can be seen in many forms such as stress, unease and many more. To address this during the interviews, it was made sure that the respondent could talk freely without disruption. Further that no sensitive question would be brought up and that the study was not interested in any information regarding talking badly about coworkers or other at the workstation. To make sure that such information would find it ways to the person in question.

3 Literature review

The literature review is, as explained in 2.3. Disposition*, to be the foundation of the thesis. It is divided into four categories; industry, technology, information, and process to make a methodical approach and guide the reader.*

3.1 Industry

The context of the industry chapter is to explain how the current industry is build up with its macro processes and highlight the main purpose of the two phases that will be in focus of this thesis, the production phase and the facility management phase.

3.1.1 Building Life Cycle and Information Life Cycle

There are many ways of describing the building processes also known as a Building Life Cycle (BLC). Nordstrand (2008) describes the process in a simplified manner with 4 phases, the phases are Specification, Product determination, Production and Product usage. Another view on the BLC is presented by Hardin & McCool (2015) that also describe it as four simplified phases called, Pre-Design, Design, Construction and Occupancy & Operation. Lastly Atkin & Brooks (2015) describes the final phase as Facility management (FM), which is a combination of operations and maintenance. Furthermore, this study will use a combined version of these three ways of describing the BLC as Requirements, Design, Production and FM phase.

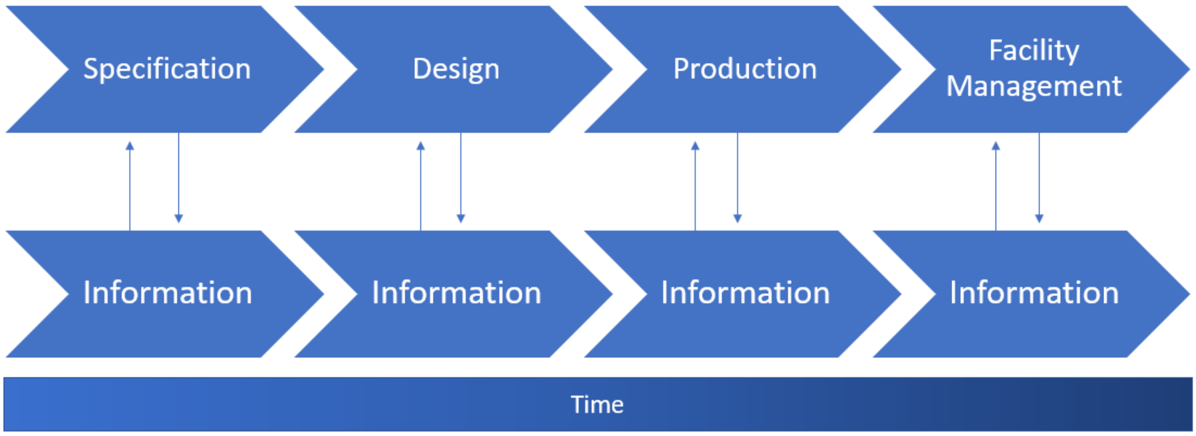

Figure 4. Building Processes along the Lifecycle. Authors own creation.

Alongside the BLC, information is gathered and created throughout the phases and later passed on to the next phase and its stakeholders (Hardin & McCool, 2015). This will further on be called the Information Life Cycle (ILC). Hardin & McCool (2015) continues by stating the value of taking the ILC into account in the early phases of a BLC and that a good process along the buildings different phases is needed to secure quality of information throughout the BLC. A concept that is used to connect the physical asset in the BLC and the information gathered and produced in the ILC is often called Digital Twin (Jones et al., 2020). Further the article of Jones et al. (2020) describe that the increased interest in the concept of Digital twin have a variety of definitions that will be described in 3.2.4 Digital Twin.

To ensure that the digital twin is up to date and reliable for the different stakeholders throughout the BLC, validation of information is needed (Hardin & McCool, 2015). Validation of construction information is a process that is used inside the production phase, and that is done in a variety of ways (Hardin & McCool, 2015). The technology that is used to validate information is described in 3.2 Technology and how the process are carried out is described in 3.4 Process. Further, the type of information that is validated and moved to the FM-phase is described in 3.3 Information. FM systems uses the information to create more efficient ways of operating and maintaining facilities. This process has substantial value to ensure a good handover of information but also the quality of information for the later phases of the BLC (Hardin & McCool, 2015). It is therefore of importance to understand how the Production and FM phases are built up and what challenges and benefits that might occur with better validation processes.

3.1.2 Production phase

One of the phases in the BLC is the production phase. During this phase multiple different organizations and stakeholders are involved to create a building that meets the requirements (Bosch-Sijtsema & Henriksson, 2014). The requirements are documents and models of how something should be constructed, this often tend to differ from the built reality (Hardin & McCool, 2015). Further Hardin & McCool (2015) continues to state that during production there is no standardized process to update the information in regards to what is built which creates a gap that grows between information and the construction. Kassem et al. (2015) describes that the problem of not updating the design information is a big challenge not only for the construction phase but for the phases after. Further the study acknowledges that processes regarding information use in FM are being addressed, but that a big challenge of the industry is that the information FM get at handover is not the same as what is built (Kassem et al., 2015).

Hardin & McCool (2015) states that in the same sense that the planning and design phase handover a foundation of information to production to increase efficiency and minimize risk, so does also production to the later phases of a BLC. Further the book states that the process of validation in production is of low quality or not existing at all. Not to mention the fact that without a process that is being used to secure information quality, there is no need for FM and owners to invest in better processes to utilize the information received at project handover (Hardin & McCool, 2015).

3.1.3 Facility Management phase

In order for FM to manage their core business, multiple sections of non-core businesses are set up to support and enable more efficient handling of the core business (Atkin & Brooks, 2015). Together the non-core business that is needed in FM build up the functions and services that provides support for the core-business and the overall performance of the organization (Kassem et al., 2015). According to Volk et al. (2014) the interest of more information in FM strive from the increased efficiency in earlier stages in the AECOO where BIM has been implemented. Both Atkin & Brooks (2015) and Kassem et al. (2015) describe that the need for more information is located in many of the FM functions such as space management, energy management, maintenance, real estate and many more, in order to enhance efficiency.

According Becerik-Gerber et al. (2012) to Implement BIM in FM there need to be an incentive or gain to capitalize on otherwise it will not be made. Lantmäteriet (2018) states that an effort to collect and use operation information in real time at school facilities in a city lowered the energy and heating cost with 40 million SEK per year. Becerik-Gerber et al. (2012) describes that the handing over of more information to

FM will enhance the usage of resources in such way that the life cycle cost for a facility can be lowered. As stated above Hardin & McCool (2015) describe the life cycle cost of a building as a split of 15 percent of cost are attributed to construction and 85 percent to the facilitating of a facility. Further Becerik-Gerber et al. (2012) acknowledges that even greater gains can be made if FM operate with correct information since they can better specify what information is needed in new building projects and therefore minimize cost for things that doesn't create value for the facility in the FM stage.

3.1.4 Key-processes of Facility Management

FM practices that are common in the organization to manage the facilities are domestic services, building maintenance, energy optimizing, maintainability and space management (Atkin & Brooks, 2015). According to Becerik-Gerber et al. (2012) the main areas where BIM in FM can create benefits are energy management, Maintenance and repair, space management, quality assurance control and many more.

Maintenance and repair can according to Becerik-Gerber et al. (2012) be described into three categories: preventive, planned and reactive maintenance. Further (Shalabi & Turkan, 2017) gives the description of preventive maintenance as a form of control to make sure that each component functions properly and that no failure can be done in a near future. Preventive maintenance is the highest form of maintenance and one that FM strive to achieve since it enables the business to function without unplanned errors. Both planned and preventive information requires information from the construction phase that manufacturers attach with the product. Whereas corrective maintenance is a response to a failure or error in a product, which is only notified by the FM via sensor information or error reports from tenants. Regardless of which type of maintenance that is carried out, information is needed to make the process efficient (Shalabi & Turkan, 2017). Lantmäteriet (2018) continues by stating that by securing information regarding maintenance, FM organizations can be more predictive and better use their resources in a preventive manner. Shalabi & Turkan (2017) continues by stating that poorly maintained Heating, Ventilation, Air Conditioning and Cooling (HVAC) systems is an example where more information is needed to have a high degree of preventive maintenance.

Energy management is according to the study of Becerik-Gerber et al. (2012) one of the most interesting areas to gain efficiency according to 82 percent of their respondents when asked about the potential of implementing BIM in FM. As stated above Lantmäteriet (2018) have seen a big gain when implementing BIM in FM to take care of real time information regarding the energy systems in buildings. Further Hardin & McCool (2015) explains that approximately 40 percent of the buildings operational cost is connected to the energy usage. Shalabi & Turkan (2017) mentions that 25 to 40 percent of the energy usage is wasted due to poorly managed HVAC systems. Becerik-Gerber et al. (2012) connect this cost to the fact that the facility owners and FM does not know that the HVAC systems in place are degraded or defective. Further, both Hardin & McCool (2015) and Shalabi & Turkan (2017) state that it would not only be cost effective to have product information and real time information systems for FM but it would also be environmentally sustainable.

Space Management is the function of maximizing the utilization of space in the building. Correctly manage a buildings space effectively is crucial for a FM to operate since most of their operations are associated with how the space is utilized. Therefore correct information about the different spaces of the facility is needed to manage the physical assets and other services that are dependent on the requirements in that space (Becerik-Gerber et al., 2012). Lately more information such as real time data captured by sensors can work as compliment to the information to make space management function more efficiently (Volk et al., 2014).

Long term maintainability is crucial for a building to function to its fullest potential throughout the life cycle of the facility without compromising the life cycle cost (Becerik-Gerber et al., 2012). Since 85 percent of the buildings lifecycle cost are made up during the facilitating of the building, a lot of effort should be put into having the FMs prerequisites in mind when in design and construction phase of a BLC (Hardin & McCool, 2015). Becerik-Gerber et al. (2012) also mention this as a function when constructing a new facility, there is an ongoing operation to make sure that defects arising from design and construction are minimized before delivery to FM. Atkin & Brooks (2015) states that the FM requirements is a need to secure information that contributes value to the rest of the BLC. Further Atkin & Brooks (2015) continues with stating that such requirements could be regarding space optimization for the type of facility in mind or specified HVAC systems that are used in the owners other buildings.

This is just some of the operations where BIM can create benefits for FM in the facilitating of buildings. Hardin & McCool (2015) address the fact that the required information that FM need to optimize its business varies depending on the type of facility as well as the type of owners. To create benefits using this information it must not only exist, but it is crucial to maintain a high quality of information and that it is correct (Shalabi & Turkan, 2017). Further Becerik-Gerber et al. (2012) continues by stating that quality of information is described by the correctness in regard to reality and that it is essential to make informed decisions in regarding operations and to increase its effectiveness. Moreover, the information that FM use to facilitate their buildings better Hardin & McCool (2015) also states that tenants and other organization are demanding higher quality of information as well. Such information that can create a higher level of service for the tenants and information regarding how sustainable the building is (Hardin & McCool, 2015).

Atkin & Brooks (2015) describes that maintaining information that enters the FM stage generates both obvious and hidden gains for the owners. Kassem et al. (2015) continues by stating that it is therefore of essence that FM companies set up systems of making sure that the information collecting, analysis, storing, updating and communication is properly managed. Whyte, Stasis, et al. (2016) continues by stating that it can simplify the process if information is collected and managed alongside the delivered physical asset and at the project close out. The information that is handed over should also be validated by client inspectors or other parties to make sure that the requested specifications are satisfied in the project handover to FM and owner (Whyte, Stasis, et al., 2016).

3.2 Technology

The chapter of technology is set up to explain what type of mechanics that is currently being introduced in the industry as it is getting more and more digitalised. It also aims to clarify in what shapes the technology can be seen in the industry and also what premises that needs to be in place in order to fully utilize the technology.

3.2.1 BIM as a concept – Benefits and barriers

Throughout this thesis the term BIM will refer to Building Information Modelling. This section will state how the thesis define BIM and what components that are important for the greater understanding of the subject of matter. BIM has different definitions, but this thesis will use the definition according to International Standards: "a shared digital representation of a built object [...] to facilitate design, construction and operation processes to form a reliable basis for decisions"(ISO29481-1, 2016). BIM Alliance (2016) describe the working process of using BIM as an object based model which connects to information from a database. MacArthur's (2015) views on BIM are similar and he stated that BIM should not be seen as a simple 3D model but rather a database of information that visualize relations between construction elements and their attributes.

Up until recent, most of the interest regarding BIM has mainly been in regard to the benefits of resource savings in design, planning and construction phases of a building (Volk et al., 2014). BIM results in benefits that could not be achieved before, but there are some barriers that hinder BIM from reaching all benefits before the barriers have been taken care of (Poljanšek, 2017). The four main barriers that are discussed are by Poljanšek (2017) are described below:

- **Technological standards** that needs to be put into place to ensure good digital quality throughout the projects. Interoperability needs to be ensured to also allow stakeholders with different systems to collaborate and take use of the information. Boverket (2020) states that their goal is to have a complete unbroken digital process in the AEC industry by 2025 to accelerate the housing market. Further Boverket (2020) explains that this will demand stricter and more clear standars as of which building rules that apply to digital building in the different processes.
- **Project owners** could be be the bottle neck of the digital implementation since it will take longer time for them to understand the technology and therefore see its benefits. Becerik-Gerber et. al. (2012) describes a growing interest in FM and the project owner since they are starting to see how information from design and production could be carried over to FM to gain value in O&M. Further the study emphasises that the information gain by FM from production need to be correct and compatible with FM information systems (Becerik-Gerber et al., 2012).
- **Shared BIM information** is a need to get more collaborative and to gain full benefits of the information gathered and used, but with this comes problems such as data ownership and liability to maintain and maintain the information.
- **All participants must be involved** to reach the benefits of large scale BIM throughout the entire value chain, this must be done without one stakeholder having the drag the change but the industry as a whole move to this direction to create change.

Poljanšek (2017), Al-Ashmori et. al. (2020) and Olawumi and Chan (2018) describe benefits and opportunities that will be acheieved when large scale BIM functions througout the life cycle of the building. Some of the benefits are increased productivity, increased certanty and multi layered communication which are described in detail below.

Increased productivity and efficiency comes from the decreased cost in locating errors in earlier stages and therefore fixing them in a stage where error fixing cost less than fixing it later in the process (Al-Ashmori et al., 2020; Olawumi & Chan, 2018; Poljanšek, 2017). As well as making it easier to asses the cost of design changes that may occur since it allows to see what type of follow up problems that would reside from the changes (Al-Ashmori et al., 2020).

Increased certainty for construction, by visualising and allowing all stakeholders to view and work with the information regarding how the construction will be carried out, minimize errors that could be clashes or misses that would hinder the build objectives (Poljanšek, 2017).

Multi layered communication is achieved throughout the process when BIM is implemented and all stakeholders have access to the same information. This enables stakeholders to not only share their own information and access others, but to also understand prerequisies for other stakeholders, thus facilitating in making decisions that benefit several involved parts (Al-Ashmori et al., 2020).

Many more benefits are described by the authors above and a majority of them are connected to cost decrease, increased productivity, increased efficiency, increased communication, better damage control, tracking of of processes and many more, all of these benefits are connected to integrated BIM (Al-Ashmori et al., 2020; Olawumi & Chan, 2018; Poljanšek, 2017). Poljanšek (2017) further continues by visualising integrated BIM as the change with highest likelyhood to be performend and also the change that will give the highest impact in the industry when performed as a complete intergrated system in all of the lifecycle of a building.

Various studies (BIM Alliance, 2016; Volk et al., 2014) have investigated and concluded the variety in complexity that a BIM-model can take shape. Volk et al. (2014) for instance utilizes the well-established LOD-figure (Level of Detail), which aims to clarify what criteria a BIM-model needs to fulfil to be classified as an even more enriched model. Meanwhile, the Swedish interest group (BIM Alliance, 2016) emphasizes a different concept aiming towards the maturity of the digital model. The concept is called BIM-maturity and aims at describing different complexity-levels of a BIM-model. Even if both the LOD and BIM-maturity might be considered dated in this field which is constantly reshaped, it is important to cover how a BIM-model is rarely a static concept in terms of details. When comparing two different models from two different projects, one could not expect the same level of detail on both.

3.2.2 Challenges of implementing BIM in the FM-phase

The benefits are clear, the reason why BIM in FM still plays a small part of the industry today is because of a set of barriers and challenges that the implementation has (Becerik-Gerber et al., 2012). Both (Kassem et al., 2015) and Becerik-Gerber et al. (2012) write a set of points that is seen as challenges for BIM in FM, that can be summarized as: lack of specifications, knowledge in FM, Interoperability between systems, information quality and lack of clarity on who is responsible. Lack of specifications is a combination of poor understanding of how BIM can help the FM and the owners not seeing the investment capabilities (Becerik-Gerber et al., 2012).

Lack of specifications derives from the absence of standards of what is needed to set up a good BIM in FM system from the owner, and that the understanding of benefits is low (Kassem et al., 2015). Becerik-Gerber et al. (2012) also states that it is unclear for the owner what amount of work that needs to be done to create a specification that grants benefits. Boverket (2020) have started the work of putting together standards of what information that is necessary in a specification, and that will help implement digital building in the future.

Knowledge regarding BIM in FM has been low but with the shift in interest regarding more information gathering in FM this can change (Volk et al., 2014). Hardin & McCool (2015) also see the shift as a beginning to a bigger need of knowledge regarding BIM in FM. The increase of interest in more information in FM is based on the knowledge of the benefits from BIM in construction and the perceived benefits in FM (Becerik-Gerber et al., 2012).

Interoperability between systems is a challenge that both Becerik-Gerber et al. (2012) and Kassem et al. (2015) see in the AECOO industry. The problem is described as a question of interoperability between the BIM systems and the systems that FM use to facilitate their buildings (Becerik-Gerber et al., 2012; Kassem et al., 2015). Further Kassem et al. (2015) continues by stating that there is a difference in the systems lifespan and how the lifecycle of a building is set up.

Lack Information quality and clarity who is responsible is a barrier since both have some points in common. The lack of clarity who's responsible for both the information gathered but also regarding the systems set in place is a challenge for BIM in FM (Kassem et al., 2015). The problem lies in the fact that with no clear roles of responsibility in each step of AECOO phases it is hard to understand who is liable for what (Kassem et al., 2015). BIM Alliance (2016) states that it can be unclear who is responsible for validating that information is correct and adjusted for FM to take over. Boverket (2020) continues by stating that systems used are connected to processes at different stakeholders with different roles in the construction. Further the report states that if one stakeholder does not carry out what is expected, other stakeholders further down in the chain tend to suffer from consequences of this.

Further challenges regarding BIM in FM exist, there is also organizational and process related challenges (Kassem et al., 2015).

3.2.3 Different phases of the modelling process

The creation of the BIM model is called modelling where a digital representation is created of a building that carries both geometric and non-geometric information and the relationship between elements (Volk et al., 2014). The modelling process is made up of multiple processes that collect previously captured building information in combination with information of how the building is set up to move forward in the lifecycle (Volk et al., 2014). The quality of communication that modelling enables between stakeholders is based on what type of information that is modelled and what complexity the model has throughout the stages in the life cycle of a building (Lin et al., 2018; Volk et al., 2014).

Modelling can be split up into four stages that are made to highlight the area of benefit and use. The four stages of a model as-required, as-planned, as-built and as-is.

As-required is seen as a digital version of the requirement specification of the building. Boverket (2020) describes that to enable a complete digital process from beginning to end in AECOO industry, the requirement specification and the additional legal information must be produced in digital form. Further Boverket (2020) explains that there is a need for a digital version of the original specifications and that the digitalization of the requirement specification enables more digital usage for later stages of models and processes. Lantmäteriet (2018) show the status for the Swedish AECOO industry in their report that stated that when it comes to digital original documents partly to none that are used. The report also states that to manage the change the AECOO need governmental systems in place to accelerate the change since it is not always the stakeholder that invest in chan.ge that gains, therefore less to none invest in this area (Lantmäteriet, 2018).

As-Planned also described as as-designed in some cases. The model is created in the design phase with the information that comes from the requirement specification that is combined with the work of the design and engineer team (Volk et al., 2014; Xiong et al., 2013). This was the first step of BIM involvement in AEC industry since the benefits of visualizing clashes between different engineering contractors saved money early in the process (Volk et al., 2014). The usage of design models have increased towards storing more information within the models such as quantification of elements, costing, time scheduling and more (Volk et al., 2014). With increased needs for information in AECOO the models have gained more and more information but without securing that the information is correct with reality (Lin et al., 2018). A new level of model was needed to match the increased demand for correct information to FM (Volk et al., 2014).

As-Built, which is seen as the next level of information modelling, can according to Whyte et al. (2016) be seen as an asset for FM. The as-built model provides information about the buildings elements and components in a precise manner (Hardin & McCool, 2015). The purpose of the as-built is to be able to pass over the information to the last phase of AECOO which is FM to help their O&M to become more efficient (Çıdık et al., 2017). The as-built information is supposed to have a higher level of detail that earlier forms of the model and therefore be able to show updated and complete information that corresponds with reality (Hardin & McCool, 2015). As Volk et al. (2014) stated, there is a growing interest for more information in the FM part since they start to see the benefits. Therefore, the demand has also grown for more effective processes to be able to sustain and safely operate their facilities (Hardin & McCool, 2015; Whyte, Stasis, et al., 2016).

The usage of high quality information in FM is said to contribute to significant savings in the life cycle of a building (Hardin & McCool, 2015). Whyte et al. (2016) express that FM heavily rely on the information that the as-built information consists of to create further value in their process. This concludes that as-built information is extremely important for FM to function in an effective manner (Becerik-Gerber et al., 2012; Hardin & McCool, 2015).

Whyte, Stasis, et al. (2016) point out that there are multiple other values of handling information throughout the life cycle of the building. By allowing information to pass over to the FM part of the life cycle leads to better understanding of what information is needed and what is missing (Whyte, Stasis, et al., 2016). Becerik-Gerber et al. (2012) present the same insight, when describing closing the loop of information, by allowing information to transfer between design, construction and end up at FM operations. Further the study explain that this information can give insights and lesson learned to new buildings in the future (Becerik-Gerber et al., 2012). To maximize the usage of as-built Whyte, Stasis, et al. (2016) highly emphasize that the As-built information needs to be put as a deliverable in the as-required documents to make sure that good quality is maintained throughout the process and during delivery.

As-Is is the final stage of the model and is similar to the as-built model in the form that is made to correct information in the model based on the changes made in the actual building (Anil et al., 2013). The model is comprised in three steps that include gathering of new information that has been changed since the as-built model, securing quality of model and securing function from the information gathered and then finalizing the model (Anil et al., 2013). The as-is and as-built have the same purpose of securing the model as a copy of the physical building but made in different stages and often by different stakeholders. Hardin & McCool (2015) argues on As-is that the model should be updated with complete information and Çıdık et al. (2017) describe that this information is handed over to FM to make O&M more efficient. The As-is takes over were the As-built are handed over according to Anil et al. (2013) which explains that changes are made after construction that also needs to be updated in the model to keep quality of information. Further the study explains that the As-is model is there to secure quality of information throughout the buildings lifecycle (Anil et al., 2013). In another study Anil et al. (2011) describe that with correct and updated information, better decisions can be made by decisions makers regarding their facilities. Atkin & Brooks (2015) continues by stating that actual and updated information is a matter of success in O&M and that is essential to respond to changes.

3.2.4 Digital Twin

The increased interest in information throughout the BLC, have increased the demand for concept that focuses on taking care of information in different phases to optimize efficiency (Boje et al., 2020). The concept of a Digital Twin (DT) was first established by Michael Grieves in 2003 during a lecture in product life-cycle, at the time virtual representation of a product was of low quality and that data gathering was an immature process (Jones et al., 2020). Grieves presented his view on a DT as a virtual representation a physical product that contains information regarding the product viewed in a life-cycle management point of view (Jones et al., 2020). This was the start for the search of what a DT is and how it can be used throughout a products life-cycle to gain benefits, this was the start to the understanding of mirroring the physical product, this concept can be seen below in Figure 5.

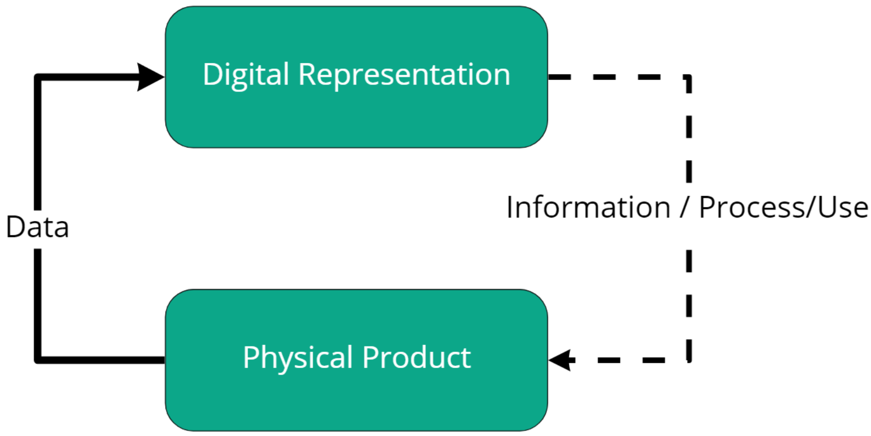

Figure 5 Mirroring with a Digital Twin (With inspiration from Jones et. al. 2020)

Jones et al. (2020) describes that the understanding of a DT and how it can benefit industries follows along with the increased interest in the subject. This led to more definitions and a variety of understandings regarding what the concept could be utilized for. This also change the way of looking at mirroring a physical product to being a twin that both contains the same information and is used to change process (Jones et al., 2020). Boje et al. (2020) describe the connection between Digital and Physical in the same way as Grieves started but with the change that the data taken from the DT is used in a managing manner to take better decisions for the business at hand. In order to clarify the concept of Digital Twin and what this entails, this study set out to explain its own combined definition that is built on the definition of (Boje et al., 2020; IBM, n.d.; Jones et al., 2020; Stojanovic et al., 2018). The definition of a digital twin in this study is as follows:

> *"A digital twin is a dynamic digital representation of a physical object or system to increase knowledge of the asset across its life-cycle."*

The definition is divided into how? when? and why? questions, The Digital representation is answering the question of how a DT should be done? This follows Jones et al. (2020) view on being a digital asset that enables better understanding of the product at hand. Further this also enables features that is not able to be managed with a physical asset, such as data gathering and analysis about different scenarios (Boje et al., 2020). When should the DT function and give value? This was established at the introduction of the concept by Michael Grieves to be spanning across the products lifecycle (Jones et al., 2020). Boje et al. (2020) continues by stating that the interest in AECOO regarding DT has increased in later stages such as O&M and that the need of information gathered in earlier stages of BLC is important to maximize business. The study sees two ways of looking at how a DT follows the BLC and is discussed further down. The last question the definition sets out to answer is why, which is answered by Stojanovic et al. (2018) that the DT enhance decision. Jones et al. (2020) also describes that the perceived benefit and reason to focus on a digital twin is to make better informed decisions. A goal for the DT is to enhance decision making as much as possible, therefore the goal of a DT is to strive to become the single source of truth (Adamenko et al., 2020). By obtaining a single source of truth the DT can reach a holistic point of view were information together can reach decisions that couldn’t be done with it being spread in multiple systems (Adamenko et al., 2020). Further Boje et al. (2020) also describes the importance of reaching a holistic approach that is scalable for it to create benefits for all the phases of the BLC. By establishing the single source of truth one can minimize time spent on cross-checking and therefore make the same informed decisions but with less effort addressing the problem at hand. As well as if the DT is established with a good interface it minimize the risk of “drowning in data” (Boje et al., 2020).

As stated above a BIM model is a form of digital representation to make better formed decision in the industry (ISO29481-1, 2016). This is then seen as a form of a DT that fits the definition established above. Further Kassem et al. (2015) describes the potential and future benefits that a BIM model can have when a flow of life cycle information is established in the usage of BIM. As well as establish processes on how to use the information in later phases than the production phase, then it will benefit the AECOO industry greatly (Kassem et al., 2015).

3.2.5 Point-Cloud

Another interesting technology that is used more and more in regards to creating spaces to attach information Is Point-Cloud (Klein et al., 2012). Further the study describes how the modelled space can be created with the use of either image scanning, laser scanning or both. The Benefits of using both is that it creates a visual layer in the model based on the pictures and points with high resolution based on the laser scanning (Klein et al., 2012). The result of a Point-Cloud is a model that both have the visual features of a picture but millions of points that can store information such as geometrical information on where it is in the room and how far it is to other points. But also Non-geometrical information can be added to this points which can add to better understanding of the objects inside of the room (Klein et al., 2012). A picture of how a point-cloud screenshot looks like can be seen in Figure 6 below:

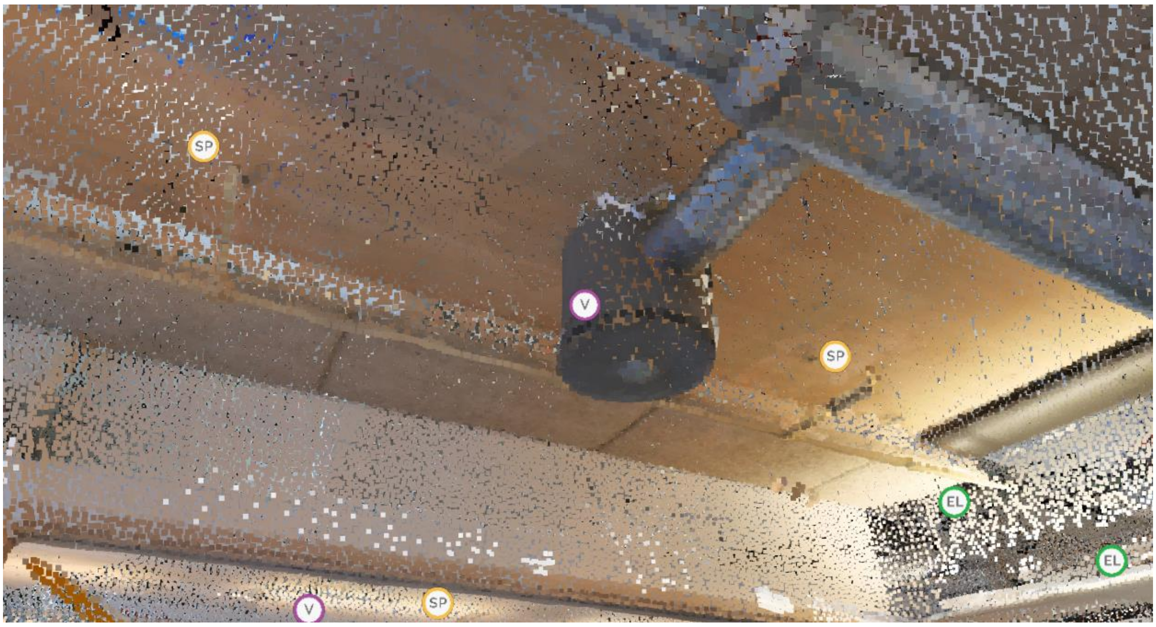

Figure 6 Point-Cloud screenshot containing HVAC system in the ceiling. (Zynka BIM, 2021)

The Point-Cloud lives up to the study definition of a DT in the sense that it is a digital representation of a physical object. The representation in combination with the usage of storing information inside points allows to increase knowledge regarding the space and therefore fit the basics for the definition. Further how the model is created and how it can benefit the information throughout the BLC is mentioned in 3.4.2 Capturing Data for Point-Cloud.

3.3 Information

The chapter of information aims to clarify how information is being handled in construction projects, different types of information issues, how one can categorize information in a more methodical approach and also how a connection between different information systems may be a necessary aspect to address.

The value of having the correct information at the right time during a project is according to Bosch-Sijtsema et al. (2020) a goal which will improve the knowledge management significantly throughout the BLC. Meanwhile, while looking at the current situation which is described, many existing buildings face a problem of not being able to access correct information due to the industry being fragmented (Boverket, 2020; Kassem et al., 2015; Volk et al., 2014). The problem is described as being a consequence due to the lacking as-built documentation which might risk putting the FM in a bad seat with increased costs of maintenance. Kassem et al. (2015) explains that for FM to be able to utilize BIM, they rely on getting correct information. When the model is inaccurate or lacks the information at all, it loses its credibility. Kassem et al. (2015) continues by stating that the problem is most likely to be a fallout of the lacking documentation of changes made during the design and production phase. Rasmussen et al. (2019) validates and extends this argument by discussing that these changes might not always be an easy task to track. However, the correct information is often existing, but is documented in mails, meeting-protocols, or other project related communications, leading to the information tending to get "locked" into the current process of the project and not delivered forward. A possible solution is by including FM much earlier in the project which would facilitate what information is relevant or critical in order to perform a well-functioning FM (Kassem et al., 2015; Koch et al., 2019). An extension of this solutions is according to Koch et al. (2019) how FM must be prepared to allocate their own resources for this early project involvement, rather than hiring external consultants to carry out the task.

The aspect of information management is also brought up by Atkin & Brooks (2015) in their book *Total Facility Management.* They argue that without information management, FM has no control over the assets they are responsible for, thus hampering a successful FM. Atkin & Brooks (2015) continues this argument by underlining the importance of how information travels from the construction process to the FM. Today, the process in abrupt, delivering most of the information along with the delivery of the facility assets, which does not facilitate learning of the assets. By instead introducing a structured information introduction, which is allocated over a period of time during the delivery, the FM would have a much easier time to adapt to and master this project specific information. This type of information procedure is according to Atkin & Brooks (2015) a fundamental step, and cannot take place after the assets are delivered. It could also benefit both the FM and the project to lean on an established Information Management Strategy, which methodically addresses how to accumulate, store, and update the information. The strategy towards information management is also addressed by Koch et al. (2019) where they argue that the client and future FM needs to be prepared to apply this strategy in order to facilitate the implementation of digitalization.

Zadeh et al. (2017) introduces five types of information issues which can occur during a construction project and develops how the five categories differ:

- **Incompleteness:** The first category is when information is absent in the model. It could be objects which are installed in the built environment but are missing in the model or assets which in the model are not assigned to a specific system.
- **Inaccuracy:** The second category is when information exists in the model but are inaccurate. It could for example be an object installed in the built environment which has a manufacturer, but in the model is documented to have another manufacturer. It could also be geometrical deviations between the model and reality.
- **Redundancy:** Redundancy appears when two assets within a model are for example named in the same way, which creates a conflict, since each object in the model needs to be unique in order to be identifiable.
- **Well-formedness:** Well-formedness is explained to be an outcome of the redundancy-issue, where the BIM-model needs to have a systematic way of naming assets in order to create uniqueness. The challenge itself lies in creating the systematic approach which must fulfil the redundancy-issue while also having a logical naming of the unique assets.
- **Understandability:** The final category is understandability. It addresses the issues that emerge when the BIM-model contains a generic object which are aimed to represent an object in the built environment but lacks information on what it represents.

The above mentioned five information-issues is a categorization which enables a methodical approach when practicing information management within a project. This creates an easier overview of making sure that project information is accessible and understandable for involved stakeholders.

The BIM-model is claimed to provide information in different forms. Volk et al. (2014) and Becerik-Gerber et al. (2012) divides the supplied information into two categories, geometrical and nongeometrical, to further address each ones purpose and how they are characterized. Both of the categories will be addressed in following sections, clarifying their function and potential benefits of providing them in a BIM-model.

3.3.1 Geometrical Information

The geometrical representation of a building is a fundamental attribute in a BIM-model, which allows a detailed visualization of assets and is argued to be e key benefit of BIM when this geometric data is accurate (Azhar, 2011). According to Poljanšek (2017) the visualization allows an increasing understanding in the complex information that a BIM-model hold, and thus could facilitate the information handling within construction projects.

The geometrical information is also a fundamental attribute to possess when practicing space management for FM (Becerik-Gerber et al., 2012). Here, an accurate BIM-model would support FM in controlling and supervising the physical aspects of the assets such as areas, and volumes. Historically, the geometric data was the main focus when data requirements where discussed, mainly due to the benefits of having geometrically localized objects within the facility, ranging from architectural elements such as walls, to more type-specific objects like electrical or plumbing objects (Becerik-Gerber et al., 2012).

3.3.2 Non-Geometrical Information

As Volk et al. (2014) explains, the power of BIM is realized when the geometrical information is enriched with non-geometric information. The non-geometric information puts a whole new dimension to the concept where objects now possess information which cannot be visually expressed. According to Lin et al. (2018) the combination of geometrical and non-geometrical information improves the AECOO processes. This especially when it comes to the As-built model, where accurate and accessible information will support the FM-processes. Importantly, Lin et al. (2018) continues by underlining how requirements of what non-geometric information to include, must come from the owner during the design stage, and later be realized in the As-built model during the construction phase.

Becerik-Gerber et al. (2012) introduces a categorization-model of different levels of non-geometrical information within the BIM-model. This is a methodical approach in how to structure this type of information in different levels and is argued to increase the quantity of data significantly along with the higher level.

Level 1 - ID and Name: The first level only refers to the entity being labeled with a unique ID-number (well-formedness) as well as a name.

Level 2 - Service Zone: The second level covers more of the geometrical location of the specified object, addressing where in the building it is located, for example in what building, floor, zone or room.

Level 3 - Group and Type: The third level is according to Becerik-Gerber et al. (2012) addressing what type of object and if it is included in a group of similar objects. The naming of types and groups are often built on industry standards. In practice, this could for example be specifying an object in being a HVAC-object of the type “HVAC-fan”.

Level 4 - Manufacturer and Vendor Data: The fourth level starts adding more individual data to the object, adding what type of manufacturer as well as serial numbers and other object-related data such when the warranty expire.

Level 5 - Specifications and Attributes: This level adds, as it implies, specifications which are related to its physical attributes such as weight, but also brings in a new dimension by adding its power consumption and what type of spare parts that it would potentially need.

Level 6 - Operation and Maintenance Data: The final level is also the one that will contain more data than any of the other levels, addressing more time-related issues and errands. This could be information such as how the object historically has been maintained or if it has been removed, replaced, or fixed throughout the years. It could also display what kind of status the object currently has.

3.3.3 Interoperability

Interoperability is a term aiming to address the opportunity to exchange information between different computer systems. More in detail, how the customer specifies for the supplier how the models should be delivered in terms of format to ensure that the model can be used in future purposes (Bosch-Sijtsema et al., 2020). The process of data sharing between systems is a difficult task to solve, which is easiest solved by introducing standards and rules in order to ensure that stakeholders can share project information in an effective manner (Kassem et al., 2015; Koch et al., 2019; Poljanšek, 2017). As noted by Volk et al. (2014) back in 2014, the interest for cooperation between stakeholders in the AECOO where increasing, but where held back, partly due to issues of interoperability. Kassem et al. (2015) explains that historically, the FM technologies and BIM-data where rarely merged to improve FM-processes. The argument seems to stem from the FM-managers inability to apply the BIM-data to FM-services since the value of BIM was not demonstrated.

According to (Poljanšek, 2017) the issue of interoperability should be a fundamental requirement in the industry and without the full interoperability, the expected impacts of more effective processes and improved collaboration will be hard to achieve. Moreover, Poljanšek (2017) adds a new dimension to the issue of interoperability by introducing semantic interoperability. Semantic interoperability differs from regular interoperability in a way that interoperability focuses on enabling the exchange of information between different systems, but semantic addresses how this information can be automatically decoded by the receiving system. In order to achieve this, Poljanšek (2017) puts attention to how both sides must utilize the same reference model and build on a fundamental concept: the same information that is sent, is the same that will be interpret. Connecting this to the current situation in the industry, Poljanšek (2017) states that the geometrical information is at a high level of interoperability, where the non-geometrical information has not come quite as far, and needs to catch up if full interoperability is to be achieved.

3.4 Process

The chapter of process aims to explain how the current process of validation is carried out in today's industry, how a potential more technological approach may look and also how gathered information needs to be delivered.

Hardin & McCool (2015) describe that the quality of information that FM receive from earlier stages such as design and construction is crucial for the efficiency of O&M. Bosch-Sijtsema et al. (2020) continue that it is a primary goal for all stakeholders to have correct information accessible at the right time and at the right process. Whyte, Stasis, et al. (2016) states that it is of importance that the information at the handover either have been validated by inspectors or other parties to make sure that the information is correct from the start of FM.

3.4.1 Validation of project information

Hardin & McCool (2015) start of by describing documentation control in construction today, as during a construction phase, 2D information increases with the timeline of the project. The 2D information is more specifically supplemental drawings, Request for Information (RFI), addendum and more. The purpose of these documents is to clarify gaps of information that might occur during the construction phase.

Traditionally this information has been in paper-form and stored on the construction site using binders and cabinets to divide the information into each discipline of work in the construction phase. The manager of these documents is called a gatekeeper and the job of a gatekeeper is to make sure that all the information is stored correctly and that every stakeholder who is in need of information have access to it. This filing system is what has traditionally been called as-built information, and an identified problem with this system of information is its scatteredness between thousands of binders and not one consecutive system (Hardin & McCool, 2015).

Hardin & McCool (2015) describes that more and more of the AEC industry is embracing paperless process to increase its efficiency. The usage of PDF drawings instead of paper drawing increases the efficiency in mapping, updating, and navigating through the files. It also helps the gatekeeper to have the correct information for every discipline updated and minimizes the strain on the role as a gatekeeper (Hardin & McCool, 2015).

Bosché et al. (2015) describe the process of validation today as visual inspections that are based on progress tracking, which is either done on a daily or weekly basis. The inspector's role is to confirm that the work that is being done meet both the contracts, scheduling and specifications. The inspector uses both logs and checklist to make sure that all work that has been done are reported for potential deficiencies or changes. This traditional practice then heavily depend on the inspectors ability to observe correct changes and correctly report them, which sets the bar for inaccurate reports very low (Bosché et al., 2015).

Hardin & McCool (2015) describe a problem caused by todays as-built information is that the existing information within the PDFs only describe the constructed information and not specific information that would improve O&M regarding the facilities. For instance, the information that often is accessible for FM is non-essential information exchanged between phases of design and construction. This does not necessarily create value for FM and only lead to an overflow of information. Also, the fixed format of PDFs or paper as as-built information makes it static and not feasible for updates such as when a new HVAC equipment is installed or when a wall is moved during refurbishment. The loss of information is big for FM since the information in this format cannot be integrated (Hardin & McCool, 2015). Whyte, Stasis, et al. (2016) Describe that these problems have made it so that new ways of updating and modifying information during the different phases of AECOO. All the way from specification to operations is looked for to help make information more dynamic and results in higher precision.

3.4.2 Capturing Data for Point-Cloud

With the increased interest in the As-Built model, more ways of gathering and capturing data has emerged to increase the correctness of the As-Built model (O'Keeffe et al., 2017). According to Klein et al. (2012), photogrammetry is one of today's promising low cost solutions for data capturing in built environment. Further the study states that the usage of photogrammetry, also known as image-based verification offers a good solution for many organizations since it requires lower skill compared to other methods while also being a portable solution. Image based verification is described as a process of producing geometric information such as distance and dimensions in areas by measuring on the photos taken. The process can be done using only one photo, multiple photos or even video images of a space, the information is then either processed manually or automatic. The process of capturing data from the images generally comes from selecting feature points in the images and then calculating based on the camera position, angle and distortion. This information can then be reconstructed into 3D models. The increased interest into this process have made it go from manual to systems that are semi-automatic. The concept of stitching is a process used where images are put together in order to create a 3D model, where the images must match with each other to be stitched and to give a correct representation. Manual stitching of images often needs less images to complete a model. While semi-automatic processes require more images that are taken with greater quality and for the systems to be able to create sufficient overlaps of the images. The final process to finalize an accurate point cloud is first an optimization of camera position in the 3D representation that creates a sparse point cloud. The model is then optimized using triangulation to find and address the same point in two layers of images taken from different perspective, which results in a relative high degree of accuracy (Klein et al., 2012).

Klein et al. (2012) acknowledges a set of problems that imaged based verification still has not fully mastered. One of these problems is that the site conditions play a big role in the quality outcome of the images. Sites need to have good lighting and be free of moving of objects before images are taken is a must to ensure quality of pixels and finding of feature points to stitch together the images. Furthermore, there are challenges regarding the lack of features that especially occur in newer buildings that often have similar room structure and uniform materials are used in multiple rooms in one building. The lack of detail in newer buildings creates a lack of visual distinction that the computer uses as patterns to recognize similarities in pictures (Klein et al., 2012).

Another increasing method to be used to gather data for the creation of models and point clouds is 3D laser scanning (Anil et al., 2011; Klein et al., 2012; Lin et al., 2018; O'Keeffe et al., 2017). Klein et al. (2012) describe 3D laser scanning as a function of light detection that is carried out by an optical sensing technology that calculates the distance from the scanners to the objects that is in the line-of-sight. Today's laser scanners can obtain millions of points in a point cloud under a short amount of time, the points are then used to generate a 3D point cloud model. The generating of a 3D point cloud model is made through commercial software that combines the collected points into an accurate view of the area that was scanned. Resolution is a term used when describing the number of points created in the scanned space, the resolution of a scan is correlated with the accuracy of point cloud, since higher resolution means smaller gaps between the points. This method for data retrieval is there for favorable when handling with objects with complex shapes or when smaller details need to be addressed (Klein et al., 2012).

However Klein et al. (2012) also describe challenges that laser scanning has. One of the challenges is the same as for imaged based data gathering, which is that it relies on the site conditions. The environmental aspect places a role in both imaged based and laser scanning since objects that may interfere with the line-of-sight will minimize the resolution the actual object at task. Another challenge that laser scanning has is that while the spatial data can be highly accurate, the accuracy is dependent on the reflectivity, surface texture and weather. Essentially this means that capturing points on surfaces such as areas with big window surfaces are not to recommend since the laser beam might not accurately reflect. Laser scanners often tend to have it hard capturing sharp edges or corners, which is crucial for certain objects in modeling. To be able to gather most accurate data from a laser scanner requires both strategic placement of the scanner in relation to its objects as well as the usage of artificial targets that the scanner can lock on to. Lastly a challenge is the cost and level of skill that is high compared to other methods of gathering up to date information (Klein et al., 2012). A comparison between laser scanning and photogrammetry can be seen in Table 2.

Table 2. A comparison of Laser scanning and photogrammetry, with inspiration from (Klein et. al., 2012)

Technology	***Laser Scanning***	***Photogrammetry***
Accuracy	Millimeter	Centimeter
Resolution	Millions of points	Hundreds of points
Equipment cost	Tens of thousands	Hundreds
Required skill	Medium-high	Low
Portability	"Bulky"	Hand held
3D data generation	Automatic capture	Post-positioning
Commercial software	Yes	Yes
3D modeling	Automatic meshing & shape extraction	Manual modeling
Environmental challenges	Reflectivity, surface texture, weather, target movement, edges, line of sight	Feature repetition, surface texture and material, view angle, line of sight

3.4.3 Information Delivery

The concept of delivering information and project knowledge is a fundamental part of the connection between project and operations according to (Whyte, Lindkvist, et al., 2016). The analogy of passing a baton is used in their research in order to visualize the challenges that a project phases during closeout. The difference is how this process is described to be a combination of several events of delivering both physical and digital assets for operations to take over. Four aspects of information delivery are highlighted which Whyte, Lindkvist, et al. (2016) argues to be addressed in order to make a successful outcome: sequence, timing, passing techniques and communication which all originates from the inspected case of the London Olympics. Further, the study identified challenges such as how to collect and merge all relevant information provided by the production-stakeholders before the project closeout as well as monitoring changes made during the project to requirements. These challenges are argued to be dealt with by extending the window of opportunity, thus for example turning sequential processes into parallel, allowing an earlier integration of operation-recourses earlier and creating a better knowledge management.

Hardin & McCool (2015) also explains that the time of planning information delivery plays a big role in the execution when the handover is about to be made. By specifying the information delivery during the planning phase of a project some factors of uncertainty can be mitigated, while changes during the project that interferes with the delivery cannot be mitigated. This creates a need for a continues delivery where information delivery is rigorously planned in the beginning but also that the process is followed up throughout the project to ensure quality of delivery. To start off there are two aspects that hinder a good information delivery process from AEC to FM. Firstly, Facility managers are often not part of the construction process and are left out of the construction teams' information and insights, which hinders the project understanding once it is finished. Secondly, the information in models and drawings does not necessarily contain information that optimize operation and management of the facility. This is mostly because of the intent for the model and drawings are to aid the construction of a facility and not operating it (Hardin & McCool, 2015).

Hardin & McCool (2015) further explains that even when a project has brought in FM in early stages and started planning the delivery long before handoff, there are still challenges that needs to be tackled early on. A challenge that is mentioned is that after the intended use of information is established, a planning regarding what information that is necessary for the operation to minimize the chances of getting information overflow that rather than helping operations hinder it. Secondly a challenge is to early make sure that the information system and data types can be implemented in the FM systems or function in a matter where the information adds value. An interoperability plan is important to test early and make sure that the information gathered can be imported to the Computerized Maintenance Management System (CMMS) or the information easily can be combined in another system to increase value of information. As a result of facing these challenges throughout a project from planning to project completion and handover. Information will be gained throughout the project and the value of information will not be lost in the different stages but rather built upon to create an increased value of the information. The continuous flow of information is described in the Figure 7 below that visualize the flow of information through project phases and how it is built up rather than lost between the phases in AECOO (Hardin & McCool, 2015).

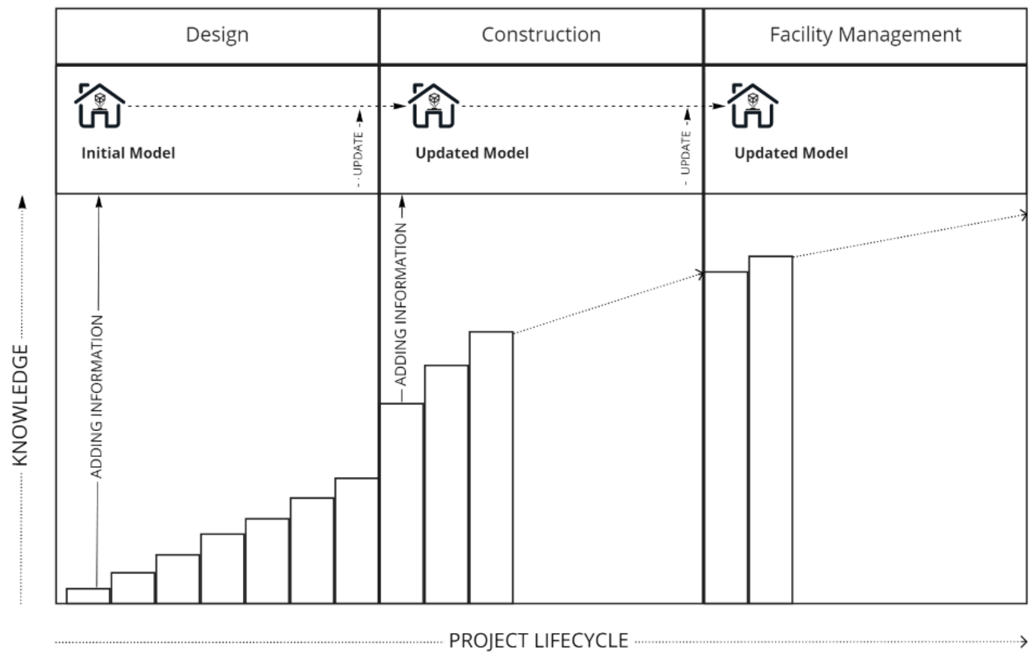

Figure 7. Gained knowledge is constantly added to the model to prevent information loss. Authors own creation with inspiration from (Hardin & McCool, 2015).

4 Case Study

The two cases that together formed the case study is here presented in the same structure that formed the literature review. The cases are aimed to be compared to be a foundation for discussion and be a motivation when later choosing what stakeholders to interview.

4.1 Case 1

Case 1 was aimed to be a facility containing several different functions, such as research, education, offices as well as a restaurant on the entrance level. The project was built between 2016 and 2020 and it contained several projects of innovation which were initiated by the client. The purpose was to evaluate if these new innovations could ease the flow of information from the construction phase of production to facility management as well as ensuring the quality of the delivered digital project information.

4.1.1 Case 1 – Industry

The origin of the innovation projects was built on a summary of the client's earlier projects which pointed at a lack of centralized standards on what to demand in terms of digital information deliveries for FM when procuring projects. This problem had led to inferior information being delivered to FM, thus creating difficulties for FM to carry out effective work. There also seemed to be an uncertainty of who was responsible for what type of information being delivered. The material leading up to the innovation projects also emphasized how the industry overall seemed to have a well-established process of utilizing BIM-information by several stakeholders like client, contractor and designers in the earlier phases of the construction project. This early involvement of stakeholders insinuated the possibility of creating the right conditions for FM later on but did not seem to be utilized. The main reason was argued to be how delivered project information was not interoperable with the FM's own processes and systems. One of the identified challenges which then were connected to the Information management was the lack of validation of project information. This therefore became one of the innovation projects for Case 1.

4.1.2 Case 1 – Technology

The Case relied on a combination of technologies to deliver a validated digital information handover. In the larger picture of the project, they wanted to avoid providing IFC-models to the FM stage since that kind of structure would complicate the validation process as well as the maintenance and use of information. It was argued that IFC-models can be compared as the PDF-files of BIM and are not suitable when revising deviations made in production or during reconstruction. It would also be a heavy workload to edit all these revisions as well as the question of who was responsible for the edits. Instead, the project turned to the technologies of laser scanning and photogrammetry. Firstly, since the design-phase provided IFC-models of the building which contained trivial information about the project. This IFC-file was then the foundation for the later coming validation, as it provided spatial coordinates for intended placements of objects. When the actual construction of the building was taking place later, the project utilized laser scanning and photogrammetry along the way in order to compare and revise the initial intended placements from the IFC-file to what was actually being built. A detailed overview of the process of information gathering can be viewed in section 4.1.4 Case 1 – Process.

In addition to the Point-Cloud, the project also utilized photogrammetry and complementary Point-Cloud scanning with handheld devices. The reasoning of this additional processes was for photogrammetry to create a visual layer in the finalized model which was going to facilitate understanding for the user. The additional Point-Cloud scanning was to document tight spaces where the ordinary laser scanner could not reach, such as in shafts. The different scanned models would then be merged into a web-based model-viewer of the Digital Twin, which was built by the consultant. The model-viewer was aimed to be the coordinating software where geometrical information would be connected to non-geometrical and together both visualize the model in form of a Digital Twin, and thus be able to provide information for example to FM-activities.

4.1.3 Case 1 – Information

The project had mainly categorized project information into two classifications, geometrical and non-geometrical information.

Geometrical information was intended to be gathered by the process of laser scanning, and photogrammetry that later would act as the framework of the model in the model-viewer. It was argued that when comparing to the current FM-documents, a laser scanned model would have a significantly higher accuracy while also being a reliable representation of the actual model. By converting the IFC-model provided by the design-phase, spatial placements of objects could be imported into the new model. The combination of scanned objects and the POIs was the foundation for validation, where objects either were verified or revised if changes in the installations had been made compared to intended placement of POIs.

Non-geometrical information was itself separated into two groups; product data (type) and specific data (individual). Generally, the product data could be described as all the information that the supplier could provide, for instance product data sheets. The specific data, however, was data which was connected to individual objects and could vary between two objects which are of the same model. Information connected to this category could be date of installation, notes from adjustment of the object, log of service and warranties.

The gathered information where then intended to be represented in the model-software in several layers. The combined informational layers were aimed to together provide a Digital Twin with intelligence both from the As-Designed and the As-Built models. Documents attached from the As-Designed model were 2D-blueprints from the AEC, as well as the IFC-model. Information attached from the As-Built model were the point-cloud and photogrammetry from three scanning stages along with validated geometrical and non-geometrical information concerning spaces and objects.

4.1.4 Case 1 – Process

Planned Process: The Image and laser scanning were supposed to be made in three stages within the facility, which is described in Figure 8. The first stage was supposed to be made directly after the foundation had been put in place, to show exactly how the building looked without any installations in it. The second stage would be performed after the objects were installed, to also offer a vision of their definite spatial occupation. The final stage would be when the interior is finished to provide a mimic of the current physical appearance. These three stages combined would together provide a visual representation of the spatial space in the as-built environment with enough insight to facilitate later processes such as FM.

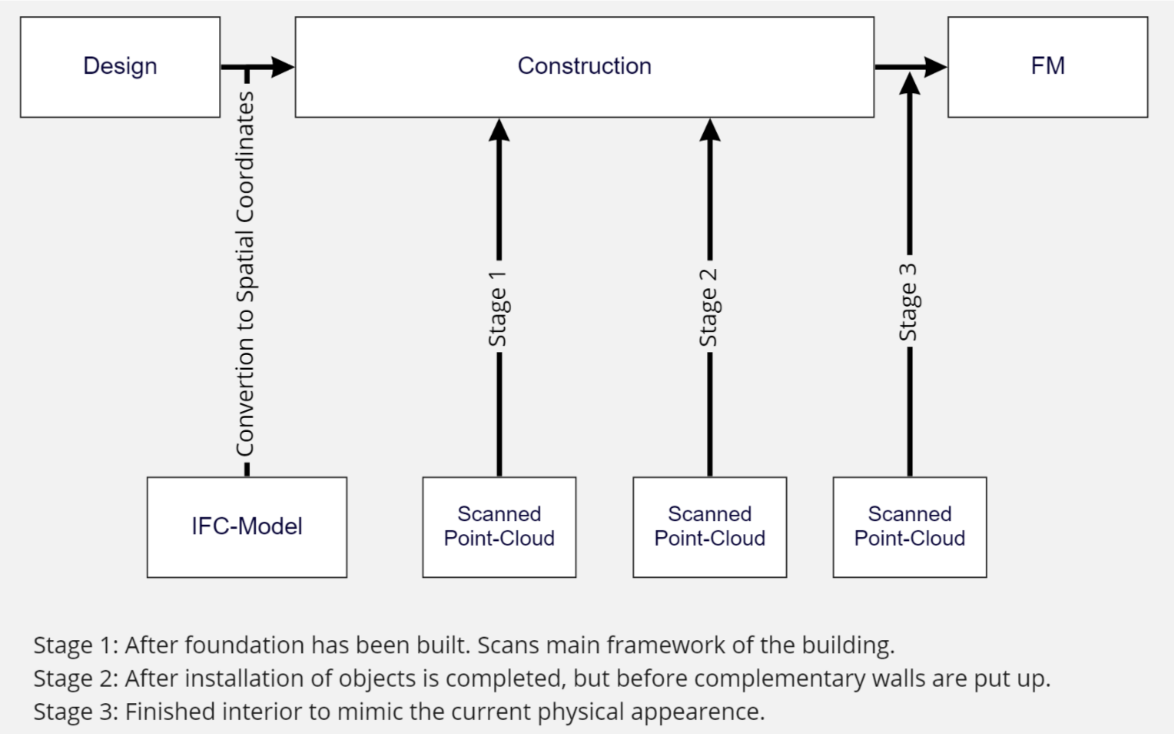

Figure 8. Scanning process of Case 1. Authors own creation

The intended validation process, which is displayed in Figure 9, started by converting and filtering the As-Designed IFC-model into a Spatial Coordinate-system. The IFC-model also enabled extraction of Points of Interest (POI) that were used as a foundation for placeholders of information in the extracted Coordinate-system. These POIs where intended spatial placements of objects, such as HVAC, doors, fire sprinkler or other objects that were considered extra important for FM and therefore needed validation. The POIs were also attached with a so-called "Type-ID" which was an ID to identify each objects type. As the Spatial Coordinate-system and POIs were imported in the model-viewer, the actual building where being built. The subcontractor installed the physical objects and ensured that the supplier had provided all product data of installed objects in the Object Database. Afterwards, the consultant would scan the building in stage 2 (from Figure 8).

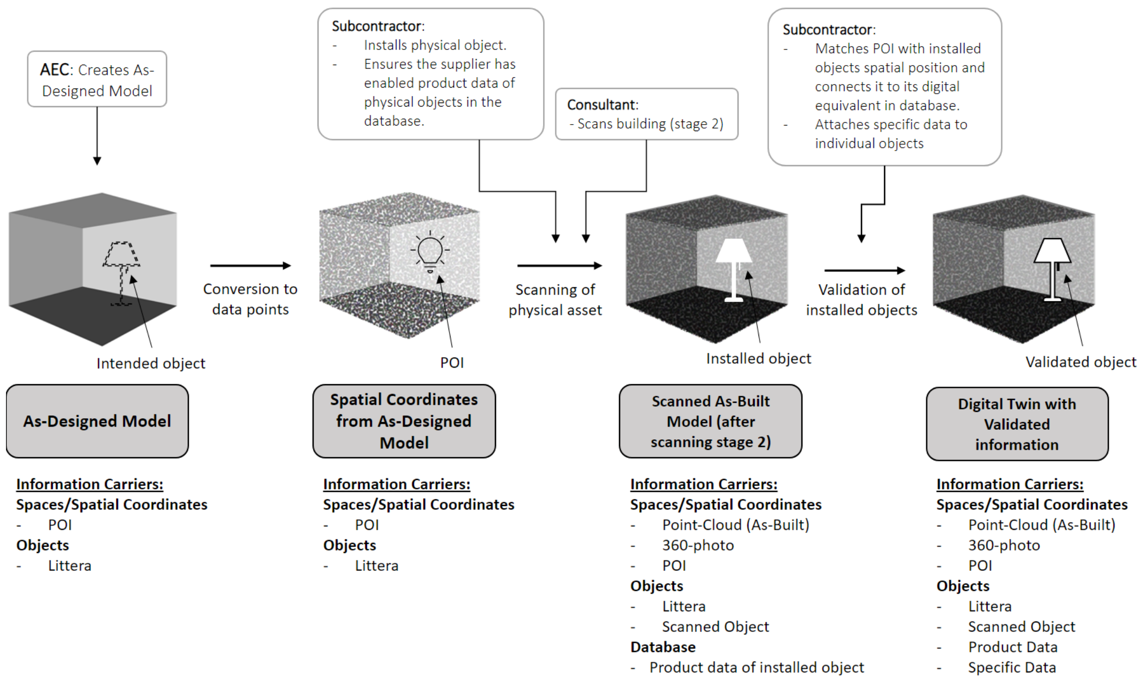

Figure 9. The intended validation process of Case 1. Authors own creation

The final step of this process would be the two-step validation carried out by the Subcontractor, demonstrated in Figure 10. The Subcontractor would access the scanned As-Built model, being able to review installed objects and compare to the POIs from the As-Designed model. After the installed object's physical position would be matched with the POI, the subcontractor would also connect this POI to the objects corresponding digital equivalent in the Object Database. The outcome would be a physically installed object with a corresponding digital twin in the model-viewer assigned with its product data. The final step would then be for the subcontractor to add specific data connected to individual objects.

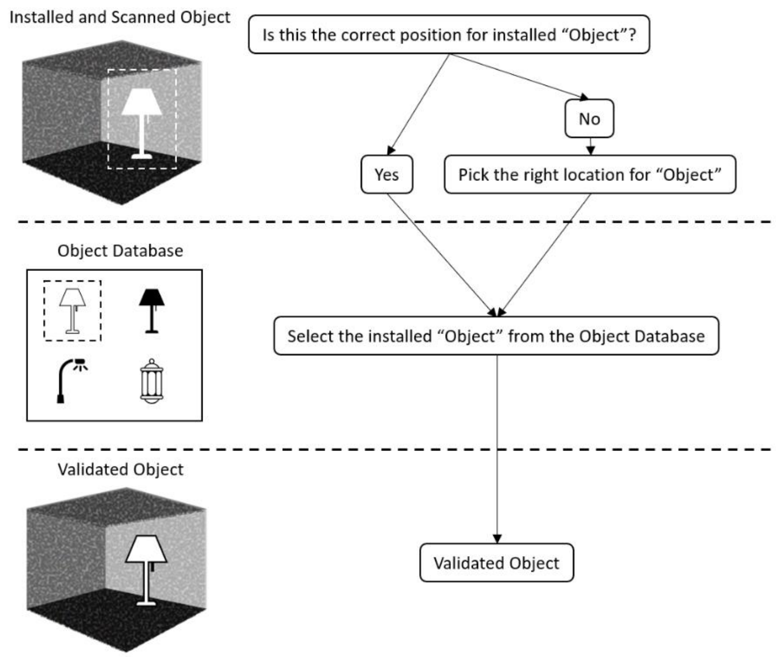

Figure 10. Subcontractors Two-Step validation of objects. Authors own creation

The Executed process both had procedures that went as planned but also some shortcomings which directly affected the process as well as the quality of the outcome. For starters, the geometrical information was collected according to the stages, described in Figure 8, where the extraction of POIs from the As-Designed model went as predicted. The three-following scanning-stages of the physical building also went as planned which paved the way for geometrical validation of assets such as floors, spaces, rooms and spatial placements of objects. Due to the different scanning stages, the scanning's also created an opportunity to visualize the projects different phases.

The process of gathering non-geometrical information, however, faced some inadequacies. The initially intended Object Database where from the beginning chosen as it was interoperable with the clients own FM-software. However, it turned out to be too advanced to use for project members of Case 1, who found it too difficult to utilize as intended. The consequence where a new Object Database, built by the consultant with cooperation from the contractor, which would contain a library of Objects installed by the subcontractors at the project. The new Object Database would help subcontractors connect product data from the suppliers to the correct object in the library. After the Object Database was established, the validation where to be performed with the help of a Validation Tool. This tool was an innovation for this specific project and were also argued by the subcontractors to not be user-friendly enough to be utilized. The validation according of objects according to Figure 10 was therefore carried out by the consultant. Since the consultant did not possess the same knowledge as the subcontractors concerning installed objects, a large amount of time went to trying to identify the physical objects and find its representative in the Object Database. The validation of objects was also carried out in larger "chunks" instead of individual objects since it was a more time-effective procedure for the consultant with probably the same outcome.

The Digital Twin at the handover of the project from production to O&M therefore contained the several layers of information that was planned for, even if the validation of objects had turned out different compared to what was planned for. It was afterwards pointed out that the handover was a crucial part for FM to gain knowledge on how to utilize the Digital Twin. Therefore, it was suggested that the handover would actively involve FM's accountable person, while also making the Digital Twin available for the whole organization as a precedent.

In an evaluation carried out after the project, four bullet points were lifted with changes that could improve the process.

1. The skill and attitude towards dealing with digital tools and processes in a project can vary significantly between different subcontractors. It is therefore of high importance that subcontractors get involved early in the process to fully establish a process which all agrees to follow. It is equally important to either involve demands in the contract with subcontractors or otherwise find incitements for the subcontractors to fully carry out the validation.
2. The number of validations can quickly become an overwhelming task if all objects are validated individually. Especially if the consultant in this case was the one in the end to carry out the validation, which made them put a lot of effort in just identifying the objects.

3. There is a high emphasize that the delivery and integration of product data is done correctly, which puts pressure on the subcontractor to follow the steps of adding product data in the Object Database.
4. Digital Twin as a concept was recommended to have a central system of handling relevant documents from the FM which would be interoperable with the model-viewer to enable information of traveling across systems of different stakeholders.

4.2 Case 2

Case 2 is a bit different compared to Case 1 since it is an ongoing project with a bit different premises. The project of case 2 is a big complex with a mix of hotel, office, retail and other social spaces which is described by the future facility owner to be a gathering point for social meetings.

4.2.1 Case 2 – Industry

The project has a couple of times been awarded for its extensive work with digital processes during design and construction phases. However, one discovered relatively late that there where potential in laying a foundation for digital processes for the O&M as well. The digital project delivery and strategy for Case 2 differed from Case 1 since the initiating stakeholder in Case 2 was the main contractor. That is why delivered information leaned more towards being relevant for the contractor's after-market and warranty processes. This of course led to a shift in what type of information that was prioritized in the project and what type of information that later would be delivered after finished construction.

4.2.2 Case 2 – Technology

The technology that was applied during the project is very much similar to the one utilized in Case 1. The foundation for the DT was a point cloud populated with POIs that was extracted from an IFC-file that came from Design in order to get a geometrical space with appurtenant placeholders. Next, the project was scanned in two phases, which is different from Case 1. The first scanning which was only on the foundation framework of the project, was canceled. This was mainly due to the fact that the consultant became involved too late in the project and did not have enough time to evaluate the scanning process enough before the timeframe for the first scanning ran out. However, the other two scanning-stages were planned to be executed as planned in order to provide the DT with point-cloud and 360-camera photos that could act as a visual x-ray of the projects different phases. For tight spaces where the scanning-machine could not access, the DT was complemented with photos taken with smartphone.

4.2.3 Case 2 – Information

As earlier described, the intended recipient of project information is different in Case 1 and Case 2 which had impact on what information that were deemed to be relevant for each case. The initiating part of Case 2, the contractor, was mainly focusing on providing information that could add value to the after-market and warranty processes of the contractor. Therefore, other type of information that could be relevant to FM were excluded or not prioritized.

4.2.4 Case 2 – Process

The scanning-process of Case 2 were as described a bit different compared to what is recommended from the consultant. Since the consultant was involved at a late stage of the project, they had little time to examine the potential cost of validating information and compare it to estimations on return of investments. However, it was decided that a limited part of the project would be validated in order to prove the impact of the process for the contractor for future projects. Even if only a limited part of the project became validated, the whole facility where scanned twice, first in stage two (according to Figure 8), and second in stage 3. This would at least give the contractors aftermarket a good visual view on the project's different phases.

4.3 Stakeholder analysis

Based on the two cases presented above, a mapping of relevant stakeholders was made according to a stakeholder analysis. The mapping included identifying what stakeholders that was directly or indirectly affected by the validation process by utilizing a power-interest matrix method (Olander & Landin, 2005). The stakeholders placements in the matrix were based on the answer of the following four questions:

- How would the stakeholder's interest be affected by a validation process?
- How would the stakeholder be able to affect the outcome of the validation?
- How does the stakeholder benefit from a validation?
- What obligations does the stakeholder have towards the validation?

Based on these four questions the stakeholders were placed in the Figure 11 to identify their relation the validation process. Based on this, a prioritization was made to interview the following four stakeholders:

- Contractor
- Subcontractor
- Client
- Facility Management

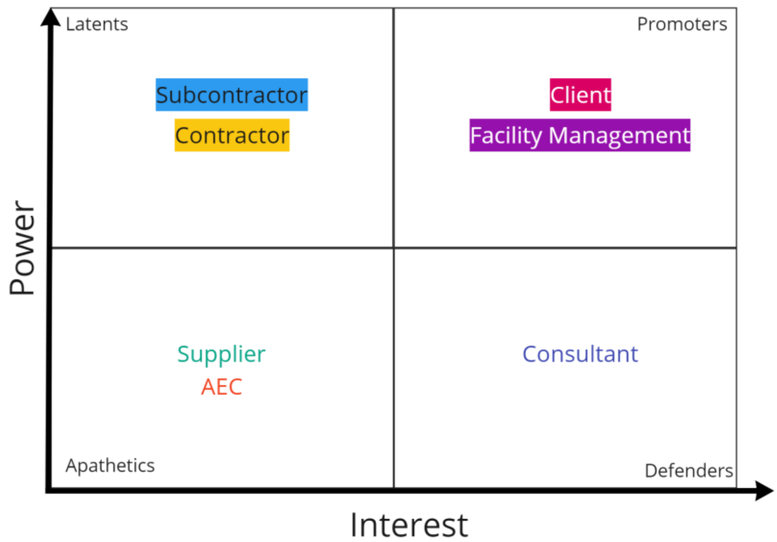

Figure 11. The power-interest matrix of involved stakeholders. With inspiration from (Olander & Landin, 2005).

5 Interview Study

In this chapter an extensive summary of the interviews will take place. The chapter is separated into four categories to follow the same structure as previous sections in this report with matching subheadings to guide the reader in the currently discussed topic.

5.1 Industry

The industry section aims to show the respondents aspects of the contexts regarding the industry's macro processes and what features that needs to be prioritized in order for the industry to embrace an implementation of a DT. Further it describes how the respondents in their area of expertise would tackle the barriers and embrace the benefits of digitalisation.

5.1.1 Digital handovers in the industry and search for automated processes

FM2 states that by moving into digital handover, they as a company can be part of the change towards the future that is happening throughout the AECOO industry. The thought of a digital handover is something that all respondents agree with, even if their answers differ in the sense of how the change should optimally be implemented and for which stakeholder it is important. FM2 further states that the benefit increases if the information handed over easily could be connected to the management systems of FM. FM2 also adds that with new technology and systems there need to be established work routines on how to properly use the new systems otherwise it will not be used efficiently.

FM2 continues to state that the cost of having a digital handover compared to a physical is not automatically more expensive, and S1 fully agree with this notion. FM2 continues to explain that the validation of information requires more labor hours from the subcontractor but that the compilation of the operation and management folders required at handover is done by consultants or the subcontractor project managers. Further FM1, FM2, S1, S2 and C2 describes that if the process can be made in such way that it exchanges the need for the operation and management folders since it is a part of the system, then economic gains can be seen.

FM1 described the ever-increasing need for automated processes since the processes they use today in combination with new systems are mostly manual work. With more systems at hand in different phases in BLC manual labor is done to make sure that the information needed for the next phase gets extracted to that phases system such as FM systems. The need for more automated resources and better implementation of new information is important.

5.1.2 Keeping the user in focus

C1, C3 and C4 displayed the same need to focus on the users of information when establishing the system and process, but C2 focus on the tenants and the information that they need to fully function in their day-to-day operations. C4 further acknowledges that the most important feature for this process to function for the technicians is to have an intuitive interface that allows easy learning and use, since it otherwise will not be used, and all the information gathered will not matter. The information therefore needs to be displayed in such manner that the operators know what they get out of it and that it is more accessible than performing a site visit to find the information on their own. C1 fills in with the statement that one of the more important aspect that he sees are the ability to connect operations to object so that FM can see what type of objects that they spend time on and to see patterns between their entire facility portfolios.

5.1.3 Addressing future problems, today

C1 discusses the problem that most of this is implemented in big new buildings that will not see the benefits of the process until many years in the future when service and operations on the facility needs to take place. This is something that needs to be considered since it will be harder to show benefits from the process to next coming projects.

C1 further mention that the pressure on environmental regulation can push the industry towards this change. Since more and more regulation regards what is inside the building to change material or objects when information more accurately about hazardous materials inside. This also connects to making sure that when a building is demolished the construction team take out all the hazardous material before demolishing. Hence more accurate information what is inside the building needs to exist. Increasing regulation regarding the need to secure building information is something that C1, C3 and FM2 all se will play a big role in how fast more information-based thinking will be used in the AECOO industry.

S1 states that he sees the work towards learning more digital technologies and working process is not a necessary yet but that it could be a market advantage in the future. Further describes that being part of innovation is interesting and that it helps to learn the direction of the industry. S2 completely agree with S1 and describes that he wants the change to happen to stop using paper and move to more modern use of 3D modelling as a tool to understand how it should be constructed.

5.2 Technology

In the following chapter the respondents' different attitudes towards used technology will be presented as well as how one must shape the technology for it to be fully utilized.

5.2.1 Perceived benefits from practise

According to FM2, who was a Project manager at a client, there where major benefits that the technology could offer for the industry, especially for the O&M. As the process of validation would lead to better knowledge and understanding of the facility, it would also enable operating services and FM to easier retrieve information through visualization and accessible interfaces compared to the old ways of using giant libraries of binders. This was also mentioned by both subcontractors, S1 and S2. They described that there were benefits of being able to see the same facility in different phases after the building was completed, from how it was designed, to the several steps captured and visualized by the scanning-process. It was argued that while being able to see installed object through a wall without tearing it down could act as very useful information. Respondent FM2 also emphasized the impact the DT would have on a bigger property portfolio, where data and information from each facility would be comparable between properties and therefore facilitate understanding of the whole portfolio in a whole new way. This would according to him really impact the way property owners run their business. In addition to this, there was a matter of significance that if the DT would be seen as a form of "Single source of truth", it would also act as a pioneer and probably gather information that otherwise would be scattered and non-accessible.

FM1, the clients Information manager, also manages to identify benefits of the technology used by the validation process. According to him, the DT is a step forward when it comes to being able to produce As-Built information and being able to compare it to the original design documents. However, while the DT were implemented into the FM-organization, new internal processes needed to be created since the DT offered new ways of working that the organization had not experienced earlier, thus needing to establish new processes in order to fully utilize the DT. FM1 also saw potential of development for the DT and its technology if one could connect other information to the DT, relevant for the FM, such as GIS-information (Geographic Information System). This would increase the useability even more for the O&M according to him. Another major factor that FM1 pointed out concerning implementing a DT into the O&M-organization was the fact that none of the staff knows how to revise or maintain the information within the DT such as the point-cloud. This implied that they would be dependent of another organization, competent enough to revise information for the O&M, thus complicating the process of maintaining information.

> *"You're not going to send a mail to Facebook, asking them to upload a picture for you on your own Facebook-page. Facebook has made it easy enough for you to upload your own pictures" – FM1 [Authors own translation]*

A possible solution according to FM1 was that the O&M somehow would be responsible for their own data and be educated enough in the matter of revising it on their own.

5.2.2 Framing technology to the user

All the contractors gave similar opinions on how they viewed the technology used for validation. Contractor C1 stated that DT is the next step after where we are today, meaning that even though many today utilized digital folders of information assembled in PDF-files, there is a next step in the evolution of this process. To this contractor it was of highest importance that the technology used would present information in a sustainable, understandable, and effective way for the user. This was pointed out in a practical manner by respondent S1 which said that there were some drawbacks when validating via smartphone, and that the software could make it difficult to validate positions sometimes. The aspect of useability was equally emphasized by two contractor respondents, C3 and C4, which also underlined how important it is to frame the technology and information based on who is going to read and utilize it. Respondent C3 also added on the topic some improvements that he as a contractor would benefit from while validating information. One improvement was the ability to search for objects in the Object Database and being able to also see similar objects that the project contained. He was also positive towards trying to create a model which carried a major part or all of the project information which would ease his job of validating information. There also seemed to be a benefit for O&M to have a running time-schedule connected to each facility which also showed time-intervals for maintenance of the installed objects. This would give the O&M an easier overlook of when certain objects needed maintenance and also easier predict costs. Subcontractor S2 also added on the topic of improvement for the DT, that one must be able to select a validated object in the DT and thus be able to highlight all the objects of the same model in the facility. This would, according to S2, improve the O&M processes. Overall, many of the contractors had a positive attitude towards the implementation of DTs and the chase of collecting case information into one single source. This under the addition that one must consider all involved stakeholders in order to establish a technology that eases processes and creates win-win situations.

5.3 Information

In the following section, the respondents' attitudes towards how project information for the process of validation is presented. Topics discussed is for example, the aspect of what type of information that is perceived relevant, as well as information gaps, interoperability, expectations on the supplier and the balance of how much information should be handled.

5.3.1 Information perceived relevant is based on project and user

The information needed to be validated is determined by most of the respondents to be heavily dependent on what type of project that is handled. Several respondents bring up objects, that are obligatory to undergo inspections during production or maintenance in O&M, to be a foundation when discussing what type of objects that are relevant for validation. Respondent FM2 mentioned that these "objects of inspection" can be foundational, which was confirmed by FM1 describing their internal demands on documenting every facility "objects of inspection" in a database. But according to FM2 there could most likely be other objects of interest that could add value to FM. He continues by stating that object information overall is of high priority when it comes to O&M processes, implying that Service & Maintenance information is highly relevant as non-geometric information to O&M. FM2 continues by stating that when implementing pilot projects in order to investigate what object that are of interest, it is important not to make the innovation project not too ambitious and rather keep in more low-key in order to fully carry out the project as intended. This opinion was also supported by respondent C4.

5.3.2 Information gaps and interoperability

FM1, that had insight into the clients O&M-processes expressed during the interview that there were some major information-gaps in the DT between what was needed from O&M and what was offered by the DT. It was mentioned that O&M today utilizes several different systems that carries their own functions and information. These systems could in one way or another could be interoperable with the DT in order to extend the DTs useability for O&M. An example mentioned was a concept called RFP (Room Function Program) which carries information about each space and it is purpose which FM1 found missing in the DT.

FM1 continued in the interview to mention the issue of interoperability which in different aspects also was brought up in the interviews with FM2, C1, C2, C4 and S1. This interoperability topic seemed highly relevant for a majority of the respondents and an underlying factor was argued to be the possibility of utilizing their own systems, that they used today, and connect it with the DT. One of the contractors, C2, wanted to implement handling of information from inspections and utilizing the DT as a tool for production-processes that was not necessarily connected to information that FM would find relevant. A majority of the respondents pushed the importance of the aspect of "Single source of truth" (SSOT) and therefore wanted to make the DT interoperable with their own systems in order to prevent same information appear on two different places, which would most likely lead to confusion. FM2 expressed it as all information already existing, it is the absence of synchronization between systems that is the problem. C1 claimed, in the light of SSOT, that all the information that is present in the DT needed to be summarized to in a description of the DT. The description, with the purpose of clarifying what type of information to expect in the DT. This would support the users of the DT understanding in what type of information that one might expect to find.

5.3.3 Expectations on the supplier

According to C4, the process of collecting product data for the validation process throughout the project did not differ much compared to the traditional way when the information was put into binders. However, the big difference came when the information needed to be processed and prepared for validation, an opinion C3, S1 and S2 agreed to. C4 argued that the suppliers that where responsible of providing product data did not have any understanding of how construction processes are carried out. This led far too often to product data being delivered as a non-workable PDF-file which made it impossible to process the information autonomously and demanded processing of data from the document into the DT manually. This was according to C4 not a big deal when it came to one object, but when scaling this problem up to a whole building, the workload became far too big of filling in more than eight parameters of data for each object in the building. C4 described this issue as a cultural problem where the suppliers needed to fully understand how their data was used, in order to provide workable data.

5.3.4 The balance of too much or too little information

In the interview with respondent C3, the contractor mentioned that information such as inspections that are crucial for production phase might not necessarily add value to the FM. However, he saw a potential use of adding this type of information in the DT anyway since it might be useful in warranty disputes or similar disagreements in the far future. In an extension of this, respondent C4 and S1 where clear in expressing the dilemma of adding far too much information in the DT, implying that an overflow of information can aggravate the process of finding correct information. S1 also pointed out that the more information demanded on each object, the greater probability of someone, somewhere connect wrong information to wrong object, which needs to be addressed when constructing the interface of the validating software.

5.4 Process

In the following section of process, the respondents' attitudes towards the scanning process and validation of information will be lifted and highlighted. This will be done both out of a practical manner from the stakeholders that have experience from the actual process, but also in a theoretical manner where potential improvements were lifted.

5.4.1 Practical aspects of scanning a building

According to FM2, C1, C2, C4 and S1 the scanning of the building went well and that the only aspect of it that changed how they worked without scanning was the fact that they sometimes need to move material for the scanner to reach. Further FM2 states that the scanning was easier than they thought and that they see the benefits of using it at their existing buildings to get a better understanding of their buildings. S1 also describe that this way of working is a higher standard than most of the industry which is great since it shows that improvement is being implemented. C3 and S2 were the only respondents that stated issues with the scanning process. They mentioned that since the different areas within the building were constructed in different speed, one cannot ensure that an entire floor is equally finished before scanning. This lead to the scanning of one floor being made in sections which could affect the quality of the point-cloud. Both further point out that this could mean that certain things will be missing since the construction cannot always wait for the scanner to come out since it cost a lot of money to not work. Another aspect that C3 describes is that the planning and execution of scanning would be even easier if the contractors themselves have knowledge of the scanning process and can execute it themselves. Since it would make communication and time planning easier.

5.4.2 The difficulty of developing a process while implementing it

Further all respondents describe different reasons why the process was not finalized as it was planned. A common understanding of why that happen was that the process was being created during the projects, and it would be helpful if the process was finalized before implementing it so a clear concept was produced at project start. This would have helped the subcontractors to clearly see what they would need to early in the project and therefore learn before it was executed inside the project. This is something that S1 empathized, that subcontractors often have a negative view of new processes that will affect them, but if a process is clear and structured from the beginning it is often much more accepted. He further explains that by presenting the purpose and what the process will create also helps the subcontractors to easier accept the process. This is also something that C2 explains that by initiating the conversation with the subcontractors early and stating the purpose more will be willing to work with the new process. Further C1 describes that just because it is a new process it does not necessarily mean more work for the subcontractors. He states that this is something that also needs to be shown to the subcontractors since it will be easier to implement if they themselves see the purpose. This is also something that S1 agrees with and states that the time that subcontractors put in creating the O&M Folders is equal to the validation process. Further he states that if the process is optimized it could even minimize time for the subcontractor.

5.4.3 Importance of communication early in the project

Regarding communication all respondents describes the need for more meetings that describes the purpose of the process, who oversees each step and what procedures that is implemented for it to work. C2 describes that it was unclear during the process who oversaw what in the different subprocesses. She believes that this is one of the reasons why the process found an early stop and that it was not continued as planned. This is also mentioned by FM2 that wants earlier communication between the consultants and both FM and the O&M. C2 further describes that this all stems from the lack of time in the project that mainly comes from that the process was being created inside the project. This is something that all respondents mentioned, the fact that the process was not ready when the project started was seen as a big reason why it the process was not executed as planned.

A paradox in the process is presented by FM2 answers, firstly to know what information that is needed one must discuss with FM what they need to make O&M more efficient. FM therefore need to be introduced early in the process to give points on what data they need and how it should be displayed for increased efficiency. The paradox is created when FM2 also states that the FM do not know what information they need to increase efficiency in their O&M. C4 describes this by saying that it is hard to know what you need when you do not know what you can get. He further explains this by a what he thinks is a Henry Ford quotation:

> *"If you would have asked people what they wanted they would have answered a faster horse, and not a car"* – C4 [Authors own translation]

This only further emphasizes the point above on that further meetings with all the stakeholders in combination with the programmers and everybody involved in creating the process. Since Only by showing all the stakeholders what they can get will spark ideas on what can be efficient. C4 further explains the other side of this as well that the programmers and creators of the software needs this communication to perfect their product since they do not know all the process when and how the information will be used.

This is further explained by C4 by introducing the benefits and what type of information the O&M personal can get out of the validation which also creates learning for them. This increases the probability for them to use the finished product after construction in the O&M processes. This is a topic that FM2 and C3 also raises the concern that if O&M personnel is not introduced early and understand the finished product and what type of information that they can extract. Then they will just go back to site visits to gain the information needed and the purpose of validation and point-cloud based method done in vain.

5.4.4 Practical aspects of validating objects

The respondents C1, C2, C4 and S2 all mention that validation of all objects in a house can be very monotone that does not create value for the FM. They all describe that some objects should be batch validated in the building. C4 states that is it not necessary to validate every single sprinkler head since it is something that will used anyway, and that it will not help O&M in their work afterwards. Although S2 sees the negative aspects of validating all the objects, he mentions that there might be a good reason if this work then could exchange the self-inspection process that they also need to do. If the assembler can use the software and easily validate during the installation and this eliminates the need for the physical self-inspection on paper. Then S2 states that this is extremely interesting and something that he thinks the industry would want. Further he states that this could minimize the creation of information that still will get lost in piles of paper that no one will look at. The exchange of self-inspection is something that FM2 also mention and sees as a big reason to continue to develop this process. Further both FM2 and S2 states that this needs to be done in such way that all assemblers understand how to do it and that it is intuitive.

C3 and S2 describes that the collection of non-geometrical information is a complicated process since every purchaser of an object is responsible for collecting the product data. This is not standardized process but rather a personalized process that changes from supplier to supplier. Both C3 and S2 describes benefits if this process were standardized, and that the information was put into the model at the moment of purchasing in form of a digital folder. Then it would help both the subcontractors when they validate objects inside the facility but also guide the suppliers in what type of information that need to be digital and how it should be transferred. This statement is also pushed by S2 that describes that if the process for the subcontractors is not as simple as a yes or no answer and that all underlying information about the product is already attached. Then it will be har to have the assemblers to validate the objects on site.

Both FM1 and FM2 raises the question about updating the information once the facility is in use and changes take place. This is an important question for the DT since it is the foundation for it to stay relevant. FM2 describes that the question was not discussed in the project and that uncertainties regarding who is in charge for updating once FM the takes over the facility and its O&M. FM1 States that this is a problem since the facilitating company wants to own the information to make good decisions for the future regarding the building and what type of systems they need. But as it is today the FM companies does not contain the right competence to facilitate and update the information when needed and therefore there is a clash. The need for better routine and knowledge transfer is big, when it comes to implementing new systems since it otherwise does not get used and loses its value. Further both FM1 and FM2 describes that this is something that needs to be sorted out for them to fully see the benefits of a DT in the long run.

6 Discussion

In this chapter, the previous studies of literature, case and interview will be compared analysed and discussed in the light of what each study have contributed with. The discussion is structured in the same way as previous chapters, with Industry, Technology, Information and Process as headlines and general guides of the discussion.

6.1 Industry

6.1.1 Increased Digitalization in AECOO

The increased need for information in AECOO is a problem that has been talked about for many years in the design and construction phase. But as Hardin & McCool (2015) describe, the need for information can be seen in the entire BLC. The respondents of the study also agree with this premise and states that it is a need that will grant a more efficient industry. It is also the base for why the cases were introduced and started, the need for innovation project is to open for new ideas and to evaluate what could create a more efficient industry. The respondents states that it is good that innovation projects take place even if they do not get finished as plan, since it is a start for the change towards using more information-based construction and O&M. As Jones et al. (2020) describe, a DT is an optimal way of gathering and securing information along the BLC and it is seen as a way of enabling ILC. The sole purpose of the case is to gather useful information in construction and to process it in such way that it enhances the O&M process carried out in the next phase. This is also something that the client respondents state the need of to become better at taking care of their tenants and the O&M personal.

6.1.2 Lack of understanding the purpose and standards

Making building processes work in a new way is a challenge, since there are many different stakeholders that have their own standards of working. Some respondents state the need for a clear process when the project start for it to both fully function but also to be accepted by all the stakeholders, especially the ones that need to change their daily routines. Both cases describe that the process was initiated late and that affected the routines and a new work process were made up on the spot, to secure that the right information from all stakeholders were considered. By trying to establish a new process along the way the respondents felt that the project was set to fail or at least not be used once the project was finished. They push for the need to have meetings regarding the purpose and routines early to establish the process within the design and construction so that FM have a good amount of time to understand how to use it once the handover takes place. This is explained as two of the four challenges for FM that Becerik-Gerber et al. (2012) explains as lack of specifications and lack of clarity who is responsible. The study further explains that standards of how to work and who´s in charge for all process along the BLC is crucial for the process to be used. This aligns well with what the respondent FM1 and FM2 stated about what they face in new projects and why some of the more innovative projects fail.

The two other challenges that Becerik-Gerber et al. (2012) presents are knowledge regarding BIM and Interoperability between systems. Both subjects are seen as crucial for the respondents and a necessity for new processes to be used after the implementation by the FM.

All the respondents see that the change towards a more information-based industry is necessary for it to become more efficient. Some respondents describe that the use of regulation can speed up the implementation time and therefore make more of the new projects implement innovative process to speed up the change in the industry. Some respondents also stated that more information can be demanded in the future for certain environment regulations that demand the facility owner to know what type of products and materials that are inside the building. This would be to secure change if a material is deemed hazardous or for other reasons. This also falls into the fact that FM do not know for sure what they need and how it can benefit them in the future which is also creates the need to try new processes.

6.1.3 Facility managers or tenants based view

Specific information needed is not something that is static and can be put onto a list. This is shown in the cases where both projects have the same process, but the main difference is who the project is meant for. One is meant to aid and help the FM after handover and the other is made to help the contractor in service and warranty errands. This is further acknowledged by the respondents that have a divided view on what stakeholder that is more important to analyze the need of information. Some respondents say that it is the user of information that is important to take into account when prioritizing information. Other respondents stated that it is the tenants need that should come first when regarding what information that is provided. It therefore not a concrete information list that can be made but a clear communication structure between all the stakeholders and the future tenants that is needed in all projects to establish what information is needed in the O&M of the facility. This takes place in the early stages of a project when it is planned what type of function the facility will have. Further a basic list can be created to function as a baseline for what FM deem to be necessary to become more efficient in their main areas such as maintenance and repair, energy management and long term maintainability (Becerik-Gerber et al., 2012). More needs of information can thereby be applied to this list and is described under 6.3 Information.

6.2 Technology

The technology that supports the validation of information in this thesis has been established during the case- and interview-study to be both innovative and ahead of the current industry. Many respondents pointed out that even if the technology is new and sometimes could come as intimidating, they saw the potential benefits the process along with the technology could have for their own cause as well as the industry's.

6.2.1 Benefits and barriers

The benefits of increased certainty & efficiency (Al-Ashmori et al., 2020; Poljanšek, 2017), productivity (Poljanšek, 2017) and multilayered communication (Al-Ashmori et al., 2020) which are mentioned in the literature are also brought up during the empirical studies. The DT are according to the interviews a far superior way of making project information accessible and understandable when comparing to the conventional delivery of information in PDF-format or physical binders. As the DT could act as a driver towards being a "Single source of truth", it would enable the forementioned multi layered communication since one single source would be able to carry project information from different parts of the BLC in terms of As-planned, As-designed, As-Built and As-Is models. By making this information accessible to several stakeholders, one would facilitate increased knowledge and learning of the project which potentially would lead to the other mentioned benefits of increased certainty, productivity and efficiency. As displayed in the interviews, knowledge from DT could be applied in both large scale such as understanding and optimizing entire real estate portfolios to small scale where individual objects and spaces in a single facility could easier be identified and understood.

As mentioned by Poljanšek (2017), the four potential barriers that could inhibit BIM and thus DT have also been identified and addressed in the empirical material of this thesis. Technological standards were mentioned in the interview with the FMs Information manager, where he claimed that the driving force for making the industry unite in one standardized model would be the governing officials. According to him, there must be a common standard if the industry wants to unite in a common way of sharing information. This would also ease the barrier that a majority of the respondents addressed during the interviews, namely the aspect of interoperability which will be discussed in 6.3 Information. The enabling of increased interoperability between DT and other systems would facilitate the search for a SSOT and once again, increase certainty when information does not exist in two separate places.

6.2.2 Addressing the complexity of a DT

The theory mentioned how the complexity of a DT as well as a BIM-model can vary depending on the case and the project (BIM Alliance, 2016; Volk et al., 2014). The variety in complexity is further discussed in the interviews where some respondents come up with potential improvements with the DT that would add information, thus improve its useability for them. This would most likely increase the complexity of the DT and contradict what other respondents said concerning useability, and how the technology must be easy enough for the user to fully benefit from the DT. There seem to be a contradiction between these two claims and a balance in trying to increase the DTs complexity while still maintaining the understandability of the information the technology provides. There is an implicit message of how the technology must be fitted to the user, and not the other way around, which is important when trying to enrich the DT even more.

An extension of the last argument could be seen in the interview with the client's respondents where they expressed how they viewed the maintenance of delivered information. They found the process and technology of maintaining information through scanning to be too complicated, which forced them to be relying on an external part. This implied, according to them, that the process chain of updating information of their own facilities became far too complex, aggravating a process that themselves could be doing with the right education.

6.3 Information

In the beginning of this thesis, the definition of a DT was presented as: *"A digital twin is a dynamic digital representation of a physical object or system to increase knowledge of the asset across its life-cycle".* Throughout the studies made in this thesis, it has been established that a DT realize *"knowledge of the asset"* partly by making it possible to select a space or point in the spatial room and attach it with information. The layers of information adding a dimension of time also enables understanding of project information and how it changed, for example between As-Designed and As-Build, which was pointed out by respondent FM1.

6.3.1 The paradox of requesting FM information

When comparing the several layers of information and connections to spatial points in a DT to a regular 2D-blueprint, this connection enables many opportunities which was not possible before. However, it has been highlighted both in the Case-studies and interviews how the "relevant" information can differ heavily between projects and is also dependent on who is going to utilize the DT. Different stakeholders find different information relevant, which is why an early project involvement of O&M as well as tenants seems to be one key-aspect if one wants to hand over the correct relevant information at project delivery. The paradoxical situation, however, is how the interviews stated that tenants or O&M rarely know right away what information to demand. In order to address this situation, a standardization might be relevant to establish, where the projects objects of interest & spaces gets connected with the different levels of non-geometric information established by (Becerik-Gerber et al., 2012). This standard would probably facilitate understanding for tenant and O&M by displaying what information of the project would be necessary, what information that could add value, what information might be irrelevant today but might be tomorrow, and lastly, what information is not relevant at all. By adding knowledge to tenant and O&M guiding them, they could make deliberate decisions earlier in the process, thus helping the validation process to earlier know what to validate.

The gathering of information, especially product information was brought up in the interviews to be a challenge that affected the validation considerably. The validation in the first case was more or less abandoned because of challenging circumstances. Every element of data for some objects needed to be manually transferred from the documents provided by the supplier, into the DT, which took a lot of time. According to one respondent, the suppliers did not understand how their provided information was implemented in the processes of the construction industry, which caused the problem. A suggestion of this situation would be to extend previous paragraphs last statement and also establish how information need to be delivered from each stakeholder in order to implement information more efficient in the DT.

6.3.2 Interoperability

In the highlight of interoperability, which was a central topic during the interviews, the aim for using the DT as a SSOT seemed to be a demand from the different stakeholders. Many respondents saw potential in adding information from their own systems that they today use in their activities, which would probably increase the useability of the DT, adding even more information. But adding more information implies also validating more information which could complicate the current process of validation. A clear mapping of who is responsible and of what information would therefore need to be established if one would implement information from other systems into the DT.

6.4 Process

As explained by Hardin & McCool (2015) the process for delivering information to the FM phase of the BLC is old and outdated in forms of paper or PDFs on USB-drive handovers and in best case scenarios folders on a server. Further the book describes the need for a more digitalized process at handover to make sure that the information is used to create value and not just stored in a room. This problem is raised by the respondents that all share the knowledge that information that is gathered and handed over often just pile up and is never used. One respondent even stated that when he came back to do warranty errands the folder was not found and that site visits were made to secure information on what was installed. This is also the whole reason for the process to take place that is presented in the case study, by increasing the accessibility and quality of information this can increase the usage of information in FM.

6.4.1 Scanning process

As stated in 4 Case Study the first step of the process was to gather geometrical data which is done with photogrammetry and scanning in combination with the IFC files gathered from the design phase. The scanning was made in three phases to get different layers for FM to later see where the installation is located via the POI location and by visually seeing the installation under the wall. All respondents mentioned that the scanning process went very well and that this part of the process was not a hinder or big change regarding to how they usually work. Only one respondent mentioned the need for planning in the scanning as a time-consuming task and that the reason was to make sure the site lived up to the condition that was needed for a good quality scanning. The respondent further mentions that another complication with the scanning is that every room on a floor does not follow the same time plan and that scanning by default become cut down in minor scans instead of a whole floor at a time. It is also mentioned that it sometimes is hard to plan in scanning at the perfect time and that sometimes installations might be missed in a scanning. Site condition is a problem that Klein et al. (2012) acknowledges and sees as a barrier for scanning as a process, and that it demand more from the contractor to make sure that when scanning consultants are booked that the site meet their requirements.

Further the study describe that a problem with scanning often occur in newer buildings that have a lot of rooms with similar structure and uniform materials in the spaces, since it makes the stitching together of images harder (Klein et al., 2012). The work made in both cases suggest that this is not seen as a problem and that the usage of geopositions gathered from the IFC files in combination with the scanning makes it easy to attach the right rooms scanning. A respondent mention that a way of making the scanning even easier and a better process can be done if the contractor themselves own the competence to scan the buildings and send the material to the consultants. By owning the competence, themselves the respondents' states that the time planning would be much simpler and if time scheduling is moved it would be easier to have the scanning be made on shorter notice.

6.4.2 Need for finished process at start of the project

As stated in 6.1 Industry the need for clearer communication throughout the process is necessary for the process to be both efficient and used by all stakeholders in the manner that it is intended to. Further by not having a clear and structured process from the beginning of the project makes it unclear and hard for all the stakeholders to understand their tasks and purpose with the process. It is as stated by Whyte, Stasis, et al. (2016) a combination of many aspect for a new process to be able to become digital and handover the correct information. The communication, timing and outcome is seen as crucial aspects when analyzing on how to create a handover process that functions well. As well as Hardin & McCool (2015) that describes planning of the delivery as crucial for it to function. This is hard when the process of handover is made during the project and cannot be correctly set up before project start. This is one of the aspects that almost all the respondents describe as a reason why the expected plan was not executed. One respondent state that if the process for subcontractors were discussed earlier, there would be no problem in executing it. But it is not easy to try something new when it is introduced late in the project and not clear on how it functions and who is responsible. All respondents understand that since it was an innovation project then it’s hard to have a clear process before project start, but they hope that it is perfected and tried from the begging in other projects.

6.4.3 The validators view on validation process

A subcontractor respondent described that the process of validating information does not need to be harder than the process that is at hand today. Further the subcontractor states that if this validation process is perfected and a routine is created for all subcontractors then it could replace the self-inspection that all assemblers need to do today. The problem is creating the process in such manner that it does not take more time than the self-inspection. The respondent further describes if all the product information can be available at assembling, then it is easy for the subcontractors to just select the product and state that the information is correct. This is what is planned in the case as the object database but for this to function the process for entering the right information need to be done better. This is also described by another respondent that describe if the contractor demands information at purchase of products in a folder, then it is made sure that the information can be put into the system before assembling. This then also follows what Hardin & McCool (2015) describe as continuous information delivery, since parts of the buildings are at different stages, continuous delivery is needed. To set up a routine for purchaser to demand product information at purchase and to teach them how to put in the information in the right folders is key for the process to become seamless. This then open doors for other ways to make the validation process more efficient but still to a high standard.

A respondent described that there is not a need to validate every single sprinkler head in the building and that with objects that have a set distance as sprinkler heads it will not differ more than a few centimeters and that the O&M personal will be able to see it anyways. Multiple respondent’s states that the usage of batch validation should be used to still validate objects non-geometrical information, but that some objects geometrical position is not crucial if it is on the exact position. As described in the case an ID is set to objects of the same kind, to categories the POIs. The respondents state that if this ID can be used to target all of kind of object then for some products all the POIs containing that ID could attach the non-geometrical information directly in order to secure information validation. The respondents describe this method to minimize the work for the subcontractors when they validate the objects.

6.4.4 Updating the DT for FM

A problem that is stated by the clients’ respondents is the fact that there was no established routine handed over on how to update the system for future renovation or changes. The clients’ further states that for them to be able to use the systems over a longer time they need to own the data and buy a system and not rent a system and lend out data. This issue is not solved or taken up in the case since it is not completely clear on how this is going to function. Just as it is not clear on should the FM have competence regarding updating and scanning. These are questions that challenge the process as it is today and is therefore great for further research.

7 Conclusion

7.1 Answers to research questions

Which information is determined to be relevant for validation in a construction project?

As it has been established throughout this thesis, what is considered relevant information to validate heavily varies depending on both what type of project is being build and who is going to be the receiver of that information. Two central stakeholders that is most likely to use the information are the tenants of the facility as well as the O&M. Therefore, their interest is highly relevant to establish in an early phase of the project to ensure correct information being delivered. Other potential users of information are for example the aftermarket from the contractor, which interest is more leaning towards warranty and service of object. What objects and spaces to validate that is perceived relevant are also varying on the same premises as the information. However, there are objects and spaces that are obligatory to undergo inspection before the project is considered finished, which is why these objects tend to be more frequently asked for to validate. Other objects and spaces could potentially add value, but is as frequently stated, heavily dependent on what project and facility is being build.

Who would be responsible for the validation and how would it be carried out?

It has been founded during this thesis that there are several stakeholders involved in the validation process. In order to establish a well-functioning process, it must exist a clear statement of who is responsible and for what. Today the scanning and creation of a point-cloud is carried out by the consultant, but in the long run, it would be a better alternative if the contractor would be responsible of this. This is because it would make the scanning more flexible, thus enabling the scanning to be carried out more often and in smaller parts when it is called for. The validation itself would the subcontractor be responsible for since they have the knowledge of what objects is being installed and therefore will make the connection between point-cloud and object database.

For the client as well as FM, it has been lifted the paradoxical dilemma of them not being able to provide what information they need. This needs to be addressed in order for the projects to be able to provide what information is considered relevant during the handover.

What impact would a validation of information have for involved stakeholders?

The goal of the validation was to facilitate processes of FM and O&M by adding more project information in a structured and understandable way from earlier processes of construction and design. It is clear that the validation has a high impact on these stakeholders of FM, but the process of validating information has been proven to also have an impact on other stakeholders as well. A validation would first of all put expectations on subcontractors to be able to adapt to this digital handling of information. This implies educating the workforce as well as needing to establish a software-tool easy enough to use. A possible incentive is to find a way for the validation to carry the same legal status as the current "self-inspection" that is carried out by paper. If the validation could replace the "self-inspection", it could eliminate making the same work twice.

The validation also had impact on the contractor. In the future, it is most likely that the scanning will be carried out by the contractor since it enables flexibility for the process. This, however, is under the condition that the scanning in fact is possible to be carried out by someone else than the consultant which is the responsible stakeholder today. A validation of project information would also enable the possibility of a digital handover from the contractor to the client by handing over the Digital Twin, which is argued to be a more structured method compared to the traditional exchange of physical binders.

7.2 Recommendations

In order to establish and later optimize a process of validating project information in a DT there are some fundamental recommendations for the industry that need to be in place first. First of all, the process need to be complete and established before the project start, in order for all involved stakeholders to understand the process and how it will be carried out. The responsibility of each stakeholder, what is being expected and what incentives there is, must also be established for all stakeholders to understand their own responsibility. This could as an example be by standardizing the gathering of object information for subcontractors and how this information is imported into the Digital Twin.

The aspect of interoperability is also a relevant topic for the industry to address. By ensuring good interoperability between the DT and stakeholders' own systems, the information will flow easier in the project and be more accessible. But firstly one must discuss what information is relevant for each stakeholder, which has been established to be a hard question to answer since it varies from project to project. Therefore it is of high relevance to establish what information that is needed in the beginning of each project.

7.3 Future Research

Firstly the thesis limited the scope to commercial real estate and its stakeholders due to this area being at the forefront of digital twins. This led to an exclusion of projects of infrastructure, that in the future might be of relevance to look at as well.

Gaps of understanding have occurred during the thesis that have sparked new questions to life that cannot all be collected in one research proposition. It is therefore of importance to continue to study the validation process and how it can become better to make the AECOO industry more efficient. For future research two questions stand out as more important to analyze and to build upon this thesis. Firstly, who will own the data? This is a question raised by all stakeholders and no one have a clear-cut solution. It would therefore be important to analyze how the different stakeholders would enable the same process but by analyzing different scenarios if different stakeholders own the data and what other processes that would be enabled. Secondly this thesis only analyzes one of many potential validation processes and it is of importance for the industry to find the most efficient process to minimize time, cost and increase quality. It would therefore be valuable to both analyze other validation processes as well as comparing the different processes to see the benefits and disbenefits that they have. This would further help the cause of creating better information flow throughout the building lifecycle.

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9 Attachment 1: Interview guide

9.1 Interview questions to Client or O&M

General Questions:

- Could you tell us about yourself and your occupation?

Project:

- Could you describe the project of "Case"?

Validation of information:

- Could you describe how the process of validating information took place in "Case"?
- What was your role in the validation?
- How did you choose what information to validate? And if you had any prioritization, how did you come up with it?
- How did you find the result of the validation?
- In experience of a client or O&M, what information do you see as valuable to validate? (Either for you or other stakeholders)
- What benefits can you identify with validating information?
- What disadvantages can you identify with validation information?
- Would you implement any changes in the validation process if you would have carried through the project once again? Can you see any changes that would carry value to you as a stakeholder?

Case 1:

- Why do you think that the validation process was not carried out as intended?

9.2 Interview questions to Main contractor

General Questions:

- Could you tell us about yourself and your occupation?

Project:

- Could you describe the project of "Case"?

Validation of information:

- Could you describe how the process of validating information took place in "Case"? What information was handled and how?
- What was your role in the validation?
- How did you find the process of validating information?
- In experience of a main contractor, what information do you see as valuable to validate? (Either for you or other stakeholders)
- What benefits can you identify with validating information?
- What disadvantages can you identify with validation information?
- What changes would you implement in the validation process if you could? Can you see any changes that would carry value to you as a stakeholder?

Case 1:

- Why do you think that the validation process was not carried out as intended?

9.3 Interview questions to Subcontractor

General Questions:

- Could you tell us about yourself and your occupation?

Project:

- Could you describe the project of "Case"?

Validation of information:

- Could you describe how the process of validating information took place in "Case"?
- What was your role in the validation?
- How did the validation process affect you as a subcontractor?
- How did you find the result of the validation?
- In experience of a subcontractor, what information do you see as valuable to validate? (Either for you or other stakeholders)
- What benefits can you identify with validating information?
- What disadvantages can you identify with validation information?
- What changes would you implement in the validation process if you could? Can you see any changes that would carry value to you as a stakeholder?

Case 1:

- Why do you think that the validation process was not carried out as intended?

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