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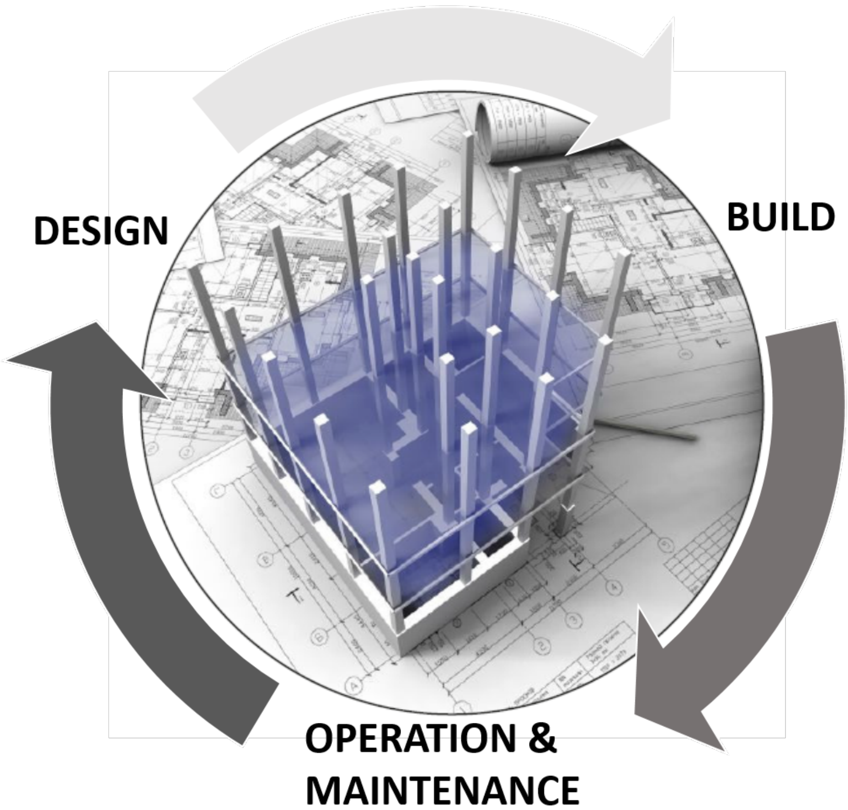


# BIM - WHAT IS BEYOND 2D DRAWINGS

A Review of the Design Phase and the Perspective of an Industry without 2D Drawings

Master's thesis in Design and Construction Project Management


MOHAMAD GHEATH KREAKER
IGNACIO RAMÍREZ VERDYGUER

Department of Architecture and Civil Engineering
CHALMERS UNIVERSITY OF TECHNOLOGY
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Supervisor: Mikael Johansson, Department of Architecture and Civil Engineering
Examiner: Mikael Johansson, Department of Architecture and Civil Engineering

Master's Thesis 2019: ACEX30-19-60
Department of Architecture and Civil Engineering
Division of Construction Management
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

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# Abstract

Building Information Modelling (BIM) can provide the Architecture, Engineering, and Construction industry (AEC) with a wide range of tools to improve the efficiency of the construction project's life-cycle. However, although the benefits that BIM technology could provide to the industry are well-known, most of those tools are seldom used and are concentrated during the design phase. The current use of BIM still involves some traditional steps that are considered as a real waste of resources. Therefore, any possible change that could lead to an increase in the use of this technology would be considered as a valuable step into a more efficient and sustainable industry. One of those steps is the use of 2D drawings that are mainly produced through BIM models. Skipping the production of 2D drawings is a potential change that the construction industry has to test in order to achieve the full potential of BIM as a working method. In order to investigate the possibility of avoiding the production of 2D drawings, qualitative research has been conducted analyzing the current use of BIM and the factors that affect its use. The reluctance of the adoption of new ideas or changes by people could be considered as the main barrier toward this implementation in the construction industry. For this reason, showing the real benefits of any change over the whole project life-cycle and the possible way to apply it in daily working activities is the key role to increase the spreading of the BIM technology and the associated benefits.

Keywords: BIM, AEC industry, 2D drawings, design phase, change theory, project life-cycle .

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# 1. Introduction

Building information modeling (BIM), is a digital model of the information that is generated and managed during a project life cycle. The information can include both physical objects, such as the different project elements, and abstract objects such as spaces, costs, time or management needs. This BIM model is a combination of technologies and organizational solutions that are expected to increase the collaboration in the construction industry and to improve the productivity within all the different project phases (Ghaffarianhoseini et al., 2017; Miettinen and Paavola, 2014).

It is important to understand that BIM does not refer only to a technological change in the construction industry, but also to a change in the construction process itself. BIM enables a project to be presented by intelligent objects. These objects contain detailed information about themselves and their relationship with other objects in the building model. BIM changes how project drawings and visualizations are generated. Moreover, it changes how all of the key processes are involved in putting a building together; starting with the early stage concepts by developing the way of capturing the clients' requirements, the analysis of different design alternatives, the collaboration between multiple design team members, the actual construction of a project, and finally the project operation and maintenance after construction (Eastman et al., 2011; Ghaffarianhoseini et al., 2017). The extension of using BIM from design to construction, and operation & building maintenance creates new levels of collaboration and interoperability increasing the efficiency of construction projects.

However, the full potential of BIM technology has not been applied yet. The Architecture, Engineering and Construction (AEC) is considered as a traditional sector in its way of dealing with new technology. Despite the current level of BIM technology most of the applications are seldom used. The use of BIM requires a certain level of knowledge acquisition and investment that not all the stakeholders of the AEC industry are willing to make yet. This reluctance of adopting new technologies restrain the general adoption of BIM technology. So far 2D drawings still dominate during the production and operation phases of construction projects. Replacing their use for BIM models would have advantages throughout the project's life cycle (Druver and Karlsson, 2018).

The production of 2D drawings is mainly during the design phase of any construction project. During this phase, despite the fact that BIM models are becoming commonly used, it is still necessary to produce 2D drawings. The great impact of the design phase on the project life cycle, whether 2D drawings or BIM models, highlights the importance of the application of the most efficient methods during this phase (Eastman et al., 2011).

This thesis examines the new potential of using BIM during the design phase and how the expected enhancement could affect projects within the Swedish construction industry. The focus of the research is on making the use of BIM during the design phase more efficient and analyzing how that would affect the different phases in the project.

## 1.1 The aim and objectives

As briefly mentioned before, the aim of this research is checking the potential improvements of using BIM in the design phase of projects in the Swedish construction industry. Checking the possibility of eliminating the production of 2D drawings in the design phase will be the main focus of this study.

The objectives of this study are to reflect around how the use of BIM during the design phase is structured, how the elimination of the 2D drawing production process affects the whole project, what are the requirements to achieve projects without 2D drawings in the future and finally suggest a set of recommendation that could lead to more efficient design phase in the construction industry.

## 1.2 Research questions

The research will focus on and answer the following questions:

- Is it possible to skip the production of 2D drawings process?
- Will this change lead to a more efficient design process?
- How can this change in the design phase be implemented?

## 1.3 Delimitation

The structure of this thesis is following typical IMRAD structure (introduction, method, results, analysis and discussion). These five parts are: theoretical background, methodology, findings, discussion, conclusion and future research.

In the theoretical background part, the concept of using BIM in both the design and construction processes is presented, as well as the definition of what BIM is and how the contractual forms can affect the use of it. BIM's level of development (LOD) took a part of the literature review for a broader understanding of the level of extension information that different BIM models could contain. The final part of the review is related to the acceptance of using new technologies such as BIM in different levels of the organizations, and how the behavior and willing of organization's members can influence the use of BIM. This part will be based on the diffusion of innovation theory and the unified theory of acceptance and use of technology.

The method part contains a general definition of the used method and the research data collection. The concept of the qualitative approach is presented and explanation of how this thesis has been carried out in addition to a brief illustration on the importance of reliability and ethics of using the collected data.

The findings section considers all the fundamental information from the interviews. Basically, this chapter summed up all main points that been discussed with the interviewees with a focus on the main thesis questions. Furthermore, this chapter aims to provide data for the following discussion section.

In the discussion chapter, the major themes of this thesis were discussed based on both the theoretical and findings parts. A match between the theory and findings parts are presented to reach the main thesis conclusion where the aim of this chapter is to provide answers to the research questions.

The final chapter of this thesis is the conclusion chapter. Its objective is to provide clear answers to the research questions and a set of suggestions that the authors believe could be useful in the future.

# 2. Theoretical background

## 2.1 What is BIM

Building Information Modelling (BIM) can be described as a range of activities in objected-oriented Computer Aided Design (CAD), that represent the 3D geometry, the functional attributes, and interactions of building elements (Ghaffarianhoseini et al., 2017). The expected result from a BIM design is a digital building model with all the data and an accurate geometry to support the conclusion of the building project (Eastman et al., 2011). Furthermore, the model has the potential to be used for operational and maintenance activities (Azhar, 2011).

### 2.1.1 Levels of BIM

BIM technology is more than just a 3D model. According to Kensek and Noble (2014), 3D models can be considered proto-BIM, digital models without the information about the elements that it is made of. A BIM model can be defined as a virtual description of a building with information about its geometry, materials, elements and even energy performance. However, depending on the extension of the information that is stake and what extent the users of the BIM models can trust the accuracy and quality of the information contained it is possible to talk about different Levels of Development (LOD). The American Institute of Architecture (AIA) has established 5 Levels of Development depending on the extension of the reliable information that a model has (Bedrick, 2008). Figure 2.1 shows the different levels of development and an example of the representation of an element.

Here are the Levels of development established by the AIA (Weygant, 2011):

- **LOD 100:** the model contains the information necessary to make a massing study of the project. It does not include any detailed or BIM elements. These models can be used to make initial budgets based on areas.
- **LOD 200:** In this level, the model includes a volumetric representation of the building elements but without the specification of which type of element they are. Some elements such as walls, floors, and ceilings can be defined but without the elements, they are made of or the materials. This LOD allows cost estimations based on areas, volumes, and quantity.
- **LOD 300:** The building elements at this stage have a well define geometry, location, orientation, and quantity. These elements may not include the specific materials they are made of. However, the model contains the necessary information to draft construction documents. Furthermore, LOD 300 models can be used for cost estimation based on components.

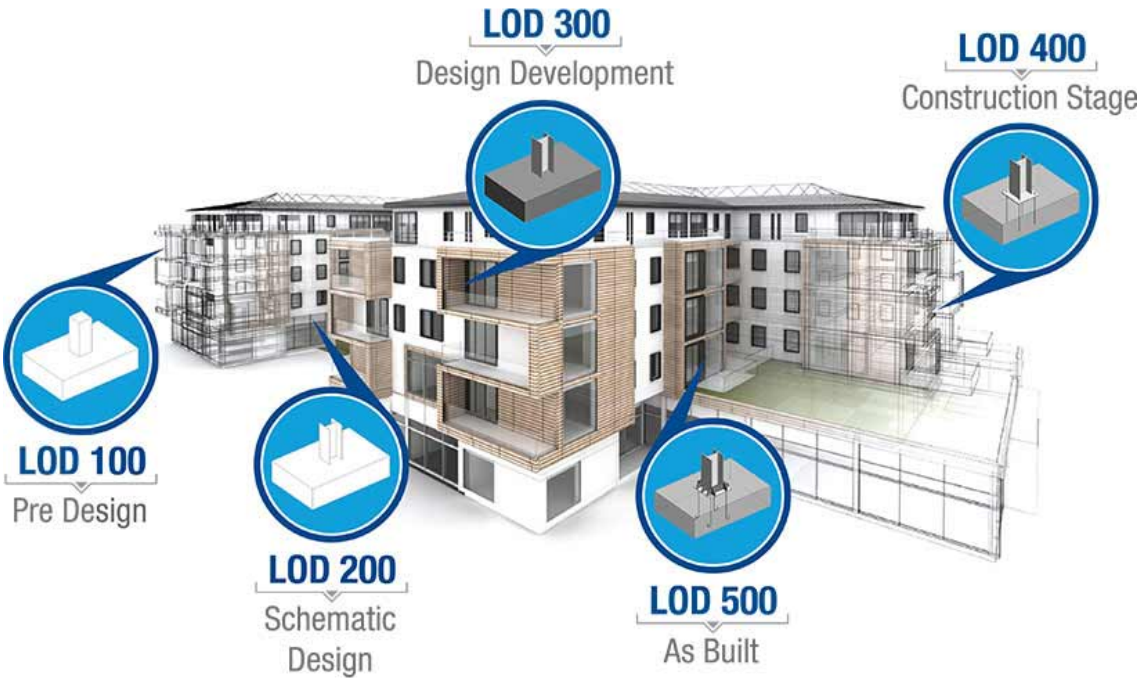


**Figure 2.1:** Levels of Development (TrueCADD, 2019).

- **LOD 400:** The elements of the building model include information about material selection, fabrication, and appropriate specifications to make an accurate budget of a project based on components. The difference between LOD 300 and LOD 400 is the amount of information about the fabrication placed on the model.
- **LOD 500:** This Level of Development requires a perfect and accurate digital representation of a building element. It cotains all the necessary information to support the Operation & Maintenance phase. In this level the BIM model is an as-built representation of the building.

### 2.1.2 Benefits of BIM

BIM is characterized for providing the Architecture, Engineering and Construction industry (AEC) with several tools to improve its activities. One of the clear benefits of BIM technology is a technical improvement with respect to regular CAD. BIM allows different disciplines to work together, using different software adapted from each discipline, but that can be combined in a single model. This new way of working allows better coordination and collaboration between the members of the design team (Ghaffarianhoseini et al., 2017). In addition, as the model incorporates information, not only regarding geometry but also properties of the building elements such as U-value, costs, specifications or materials, it can be used by different stakeholders of the project.

The main benefits of BIM technology are the following:

- **Better Collaboration and Communication:** BIM models allow for sharing and collaborating, between the different disciplines in projects. Cloud-based models improve the BIM collaboration creating a common platform to share project models and coordinate planning, ensuring all project members have insight into the project (Ghaffarianhoseini et al., 2017).

- **Improving coordination and clash detection:** The possibility of integrating the different discipline models in a common one allows a clash detection process and a common review of the project (Eastman et al., 2011). However, it is crucial to encourage collaboration and discourage the isolated working of the design team members (Anderson O. and Zulfikar A., 2017).

- **Improving scheduling:** Another benefit of BIM technology is the application of BIM 4D for coordination and scheduling. As the models include information regarding materials, quantities, and even product models, all building elements can be ordered electronically and delivered on time, which can improve site logistics and material deliveries (Eastman et al., 2011; Ghaffarianhoseini et al., 2017). The building elements can be grouped and assigned in different project activities. Among other benefits, this process allows better collaboration between contractors and designers as contractors can provide their experience at an early stage of the project, and give feedback about the feasibility of the project plan. Moreover, the 4D model can be used to compare schedules and to improve the monitoring of the construction process (Eastman et al., 2011).

- **Extract cost estimations:** BIM technology can be used to extract an accurate list of quantities and spaces that is useful to do cost estimation. Thanks to this tool it is possible to obtain a detailed budget of the project and keep all parties aware of the cost implications associated with a given design. As a result, the decision-making process could be improved, making possible to take better-informed design decisions regarding costs using BIM models (Eastman et al., 2011). When a BIM model contains both scheduling and cost estimation it is considered a 5D model (Ghaffarianhoseini et al., 2017).

- **Building Performance:** BIM technology provides a wide range of tools to improve the design process. One of the most common tools is the analysis tool. The different disciplines use their own software. Starting from structural analysis to energy performance there is various software that can calculate the performance of the buildings using 3D models(Eastman et al., 2011).

- **Visualization:** BIM technology allows o plan and visualizes the project in advance. Space-use simulations and 3D visualizations allow clients to experience what space will look like increasing the opportunity to make changes before the construction phase. The possibility of having an early overview minimizes expensive and time-consuming changes later (Ghaffarianhoseini et al., 2017).

### 2.1.3 Virtual Design and Construction

Virtual Design and Construction (VDC) is a broader term of the use of BIM that has the objective to achieve the full potential of this technology. This concept links all the advantages that the BIM tools can provide with the management approaches of construction processes (Gustafsson et al., 2015). Fischer and Kunz (2004) define VDC as *"the use of multi-disciplinary performance models of design-construction projects, including the Product (i.e., facilities), Work Processes and Organization of the design - construction - operation team in order to support business objectives"*. The idea behind VDC is not just only the creation of an information platform but also use this information to simulate and predict the challenges, risks, and opportunities of construction projects before the real project starts. Despite there is no clear division between where BIM ends and VDC starts (Gustafsson et al., 2015), VDC is understood more as a way of working, dealing with technology and management together (NCC, 2019) instead of just a collection of new technological tools.

## 2.2 The use of BIM in the Design Process

The design phase could be considered as the most important phase of a project regarding its further contribution to the project life-cycle. During this phase, cost and resources estimations, modeling, and planning are set (Maylor, 2003). In recent years, BIM technology has been focused on the design phase because it is considered the stage of the project where most of the elements are defined and most of the information is provided. This technology has transformed the design process by replacing the traditionally 2D drawings for 3D building models. The application of 3D models, among other things, allows seeing the correlation between the work of the different disciplines involved in a project and encouraging the design information transference. Furthermore, complete 3D models allow better coordination between different project participants. It would reduce errors and improve the quality of the design (Eastman et al., 2011).

The use of BIM has a different impact depending on the stage of the design process. The first stage of the design process is **conceptual design or pre-design**. This stage consists of the collection of the basic information about the project, the client's requirements, and in which conditions the project would be developed. Furthermore, during this stage, the selection of the contractor would be made by the client and the design team would be formed. The most important parties involved in this stage are architects, contractors, and clients (De Cos Castillo, 1997). During this phase BIM acts as a visualizing tool, helping the communication between the actors involved. The level of Development of the model is usually LOD 200.

The next stage is the **schematic design**. In this stage, the scope definition and the time estimation, in addition to the budget would be drafted (De Cos Castillo, 1997). Both architects and engineers have to collaborate in order to establish a realistic and accurate schematic design, schedule, and budget. The more available information during this stage, the clearer the project scope would be. This means that fewer changes would be needed in further stages. Early changes during this process will be less costly than changes in further stages (Broberg, 2018).

Figure 2.2 shows the distribution curve of effort/effect that activity has all over the different phases of a construction project. Curve 1 reflects the ability of designers to make changes. At the beginning of the project, during the pre-design phase, it is easier to make changes in the design as it is still conceptual. However, as the graphic shows, during the construction phase, this possibility decreases. Curve 2 shows the cost of the changes. As the figure shows, it is extremely costly to make changes in the latest phases of the project, during the construction phase.

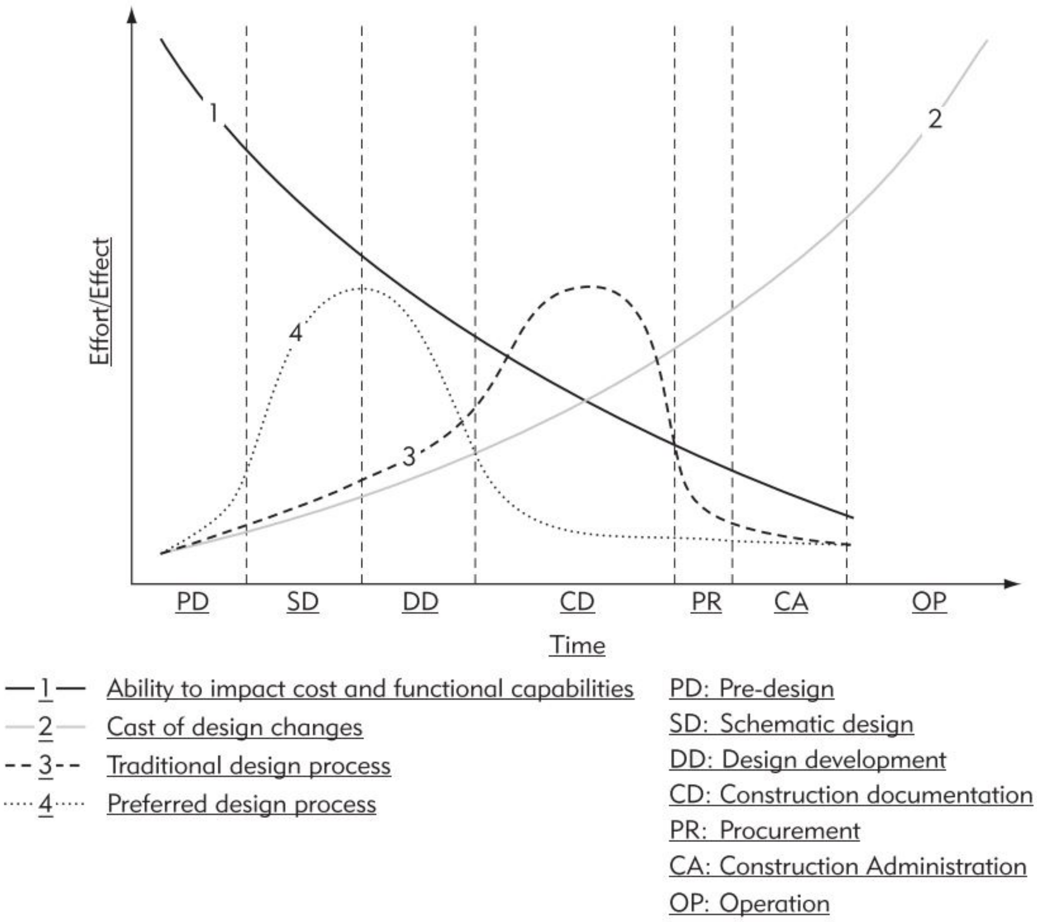


**Figure 2.2:** Distribution curves of cost and effort during the different phases of a construction project (Eastman et al., 2011).

The last stage of the design process is the **detailed design and developing construction-level information**. All the disciplines involved in the project have to produce the necessary documentation to accomplish the project as well as the information that would be needed during the construction phase. The result of this stage is the final models and drawings including the project systems descriptions. All these documentation and information are required on site to successfully accomplish the project and have to be delivered by the design team (De Cos Castillo, 1997). BIM plays a key role during this stage and the schematic design. It improves the collaboration and the information sharing between the design team members increasing the quality of the design and reducing the conflicts. At the end of the design phase, the models usually achieve a LOD between 300 and 400. Models contain all the construction material and information and, in some cases, the manufacturing information. It is uncommon to reach a higher LOD because of the volume of visual information and data that is not practical to use (Weygant, 2011).

Traditionally, all the documentation has been delivered in printed papers. Nowadays the project documentation is delivered in PDF format with the BIM models as a compliment, being them the information carriers. However, they are not contractual documents so they do not have legal validity (Druver and Karlsson, 2018). The documentation has to be created from the model in addition to the model creation process. A study has been conducted in the construction industry to make the time spent on producing 2D drawings out of models visible, and the result of the study came up that the average time to produce 2D drawings from models is approximately 40% of the design phase and this process includes creating the 2D drawings, control and ensure drawings' quality (Druver and Karlsson, 2018).

## 2.3 The use of BIM in the Construction Process

The benefits from the BIM technology have been associated with the design phase. However, this technology provides tools for the project team to enhance collaboration and improve construction management.

In order to increase the value that BIM technology provides to contractors, it is necessary that BIM model contains additional information than the necessary for the strict design. According to Eastman et al. (2011), a building model should provide contractors with the following information:

- **Detailed building information** where the contractor can extract quantities and information about the building elements. All the elements that are involved in the project should be specified in the model.
- **Temporary components** that are important for the planning and the logistics of the construction site.
- **Analysis of data related to performance levels and project requirements.** Specifications of loads, heating and cooling demands, etc.

Traditionally, as designers and contractors work separately, the contractor has to create its own model based on the information provided by designers. Figure 2.3 describe the process flow where the contractor receives the information about the project from the design phase and update or create a new model with the specific information that is useful for the construction phase. These models are used for visualization and construction planning while it has not been common to use them for procurement or quantity takeoff (Eastman et al., 2011).

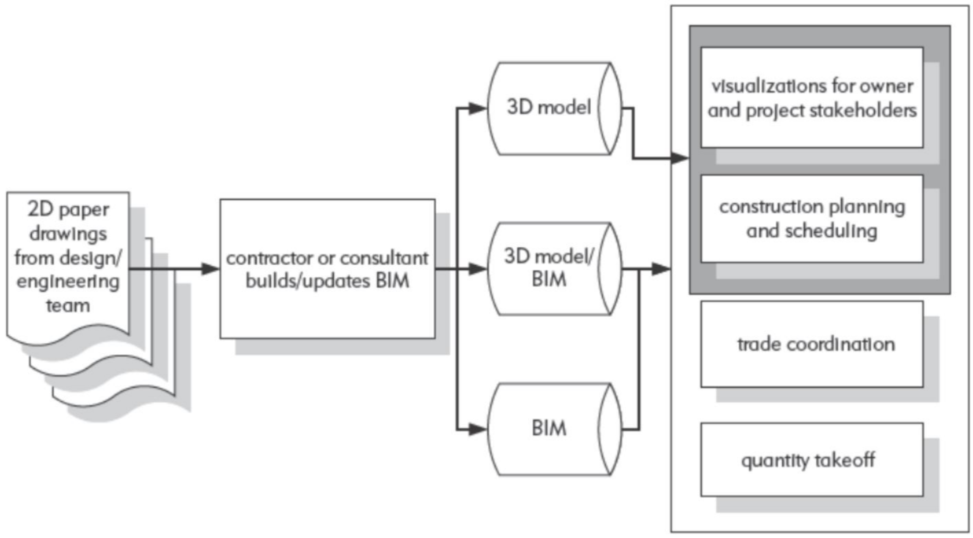


**Figure 2.3:** Process flow where the contractor builds its own model based on the information from the design team (Eastman et al., 2011).

Another approach of a process flow has been presented by Eastman et al. (2011) (see figure 2.4). Based on this approach, the contractor is early involved in the design process and being part of the developing of the shared model. The advantages of this method are time-saving and the creation of a more detailed model. However, this type of working strategy requires efficient coordination between the project participants in order to keep the models updated.

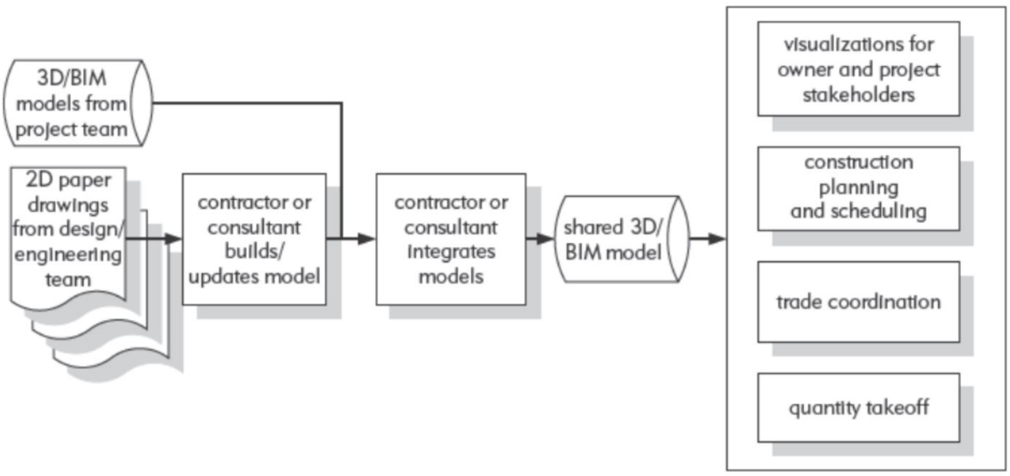


**Figure 2.4:** Process flow where the contractor is involved in the development of a common BIM model (Eastman et al., 2011).

### 2.3.1 BIM on the construction site

As the BIM technology in moving forward, one of the challenges to extend its use in the production phase is to move the BIM tools to construction sites. The idea is to improve the access and availability of information on the construction site (Murvold et al., 2016). 3D models help to visualize and solve problems on site and are considered a good complement to the traditional 2D-drawings. Increase the use of BIM models on site would improve the identification of errors, possible problems, helps the incorporation of new workers and a better understanding of the project (Murvold et al., 2016; Simey, 2013).

In order to achieve the full potential of using 3D models on construction sites, some obstacles should be solved. The workers' accessibility to the 3D models is considered as one of them. To solve this kind of problem, some ideas have been implemented. One idea is the implementation of BIM-stations on the construction sites where workers have access to the station to get the needed information from BIM models. According to Murvold et al. (2016), BIM-stations helps to visualize the project and provide easy access to the updated drawings, leading to increase in the productivity of the construction phase. The construction workers pointed out the effectiveness of this solution to extract the necessary information for their daily activities. On the other hand, these stations cannot place all the time close to the working place, so construction workers have to spend the time to get there. Furthermore, Construction workers, in general, have a positive attitude towards the use of BIM. However, they usually do not possess the necessary skills or knowledge to use it (Brantitsa and Noberg, 2018). For this reason, it is important to increase the formation of the workers, and the level of detail of the models in order to extract the full potential of this technology.

Another solution has been implemented during the reinforcement works of Oslo airport terminal 2, in Norway. During this phase, the work was based on digital models displayed on handled devices such as iPads. This solution considered to be more convenient than working based on paper drawings since all project data was stored in one single location. The Productivity of the reinforcement work was increased by BIM on site providing a better foundation for deciding upon assembly sequences (Merschbrock and Rolfsen, 2016). The application of this solution faced two obstacles, the first one was the use of fragile devices like iPads was not an efficient way and especially during the cold weather in Oslo, and the second one was the lack of IT capabilities of using on-site BIM. According to Merschbrock and Rolfsen (2016), the practical implementation of on-site BIM will continue to be uncommon unless the construction industry succeeds in increasing its IT capabilities and in using the appropriate contracts for BIM use (Merschbrock and Rolfsen, 2016).

## 2.4 Contract Implications

The contractual forms play a key factor in deciding which level of BIM could be implemented during projects. Nowadays, there are three mainly contractual methods that are used in the construction industry: Design-Bid-Build, Design-Build, and Integrated Project Delivery (IPD) each of them has different implications and affects the use of BIM in a project.

- **Design-Bid-Build:** it is known as the traditional method where clients hire a design firm that presents a design proposal. The next step after the design proposal is a bidding process to choose the contractor responsible for the construction phase of the project. In this contractual form, there is a clear division between the design and the construction phases. The collaboration between the responsible for each phase is limited. According to Su-Ling et al. (2018), there are three main limitations that restrict the use of BIM: first, there is no guarantee that all the disciplines would use compatible software, limiting the interdisciplinary collaboration. Secondly, as this contractual form define the responsibility of each stakeholder, there are no incentives to be involved further than your responsibility. And finally, Design-Bid-Build contracts restrict the participation of the contractor to the construction phase, canceling the participation of it on the design phase. All these limitations restrict the potential of the BIM technology.
- **Design-Build:** this contract method is based on hiring a main contractor responsible for both the design and the construction phase of a project. Since both parties, designer and contractor, are required to function as a team then the collaboration is highly demanding. Also, sociological change from projects' teams is required to achieve project success. This collaboration will be based on trust instead of traditional roles and responsibilities (Hardin and McCool, 2015). This method opens the opportunity to fully leverage BIM tools and practice. With design-build method, BIM models can evolve during the entire design, so efforts are not doubled between the design and construction phases.
- **Integrated Project Delivery:** it is a new type of contract based on the collaboration of owners, designers, and contractors of a project. This contractual form was introduced by the American Institute of Architects (AIA) as a response of the negative relationship between stakeholders that arise in the other contracts styles (Marco and Karzouna, 2018). In this type of contract, the stakeholders establish a common goal and the allocation of costs and risks. Both the potential benefits or risks are shared allowing an encouraging better collaboration between the actors involved. Among other benefits, this type of contract allows a sooner implication of the contractors on the design as well as encourage the designers not to only focus on the design but also on the construction performance (Eastman et al., 2011). As this method is based on the high collaboration between the project participants, so BIM can be implemented perfectly with it. All project teams will have a clear understanding of the model and which method will be used to exchange information between participants and models.BIM Model will be developed throughout the

whole design phase which allows the design team to be proactive with issues as opposed to reactive (Hardin and McCool, 2015).

## 2.5 BIM for Operations & Maintenance

During the life-cycle of building the operation and maintenance (O&M) process constitutes around 60 to 80% of the building cost. However, it is not an important focus during the design and construction process (Akcamete et al., 2010; Nicał and Wodyński, 2016). O&M management information traditionally comes from the completion documents in the form of unstructured digital files, drawings, and documents. This delivery makes the search for useful information as a complicated and hard process, especially in large-scale projects. Therefore, the digitalization of project information became an urgent task to facilitate the intelligent management of the O&M systems. Nowadays, the as-built information models in the construction projects contain geometrical information and construction-related data, but there is still a lack of useful information for operation and maintenance management (Hu et al., 2018). The more information the models contain the more benefits can be achieved on the O&M phase of the buildings. This is the next step of the BIM technology so it can be applied all over the project life cy cle.

If a BIM model contains the necessary information, then it can be used as an integrated view and information database about the facility systems. Unlike the traditional documentation, the BIM models are a single source of information and representation that makes it easier to analyze the systems as a whole. Nowadays, Maintenance departments use Computerized Maintenance and Management Systems (CMMS) or Computer Aided Facility Management (CAFM) for maintenance purposes. However, to achieve all the potential of this kind of software all the information related to maintenance space and elements has to be provided to the software. BIM models can transfer all the information regarding the building elements, including maintenance spaces and characteristics, to the maintenance software. Thanks to this the time spent in creating and updating the maintenance databases is considerable reduced (Akcamete et al., 2010). According to Eastman et al. (2011), The US Coast Guard Facility Planning reports 98% of time-saving thanks to the use of BIM models.

However, in order to simplify the communication process between the different BIM tools, it is important to use a standard format that allows transference data regardless of the software or the version of it. In the ACE industry, the most common format is the *Industry Foundation Classes (IFC)* format. This format allows having access to the information even if the software used to generate it is obsolete. Also, it is a start point to standardize the information that should be included in the models.

## 2.6 Theories of Change

### 2.6.1 Diffusion of Innovation

Diffusion is the process of spreading innovation to a group through specific channels. Innovation is a technology that is perceived as new by the group how is adopting it. As figure 2.5 shows, any innovation diffusion process starts through a group of people (the innovators) that have the resources and are willing to try new ideas and implement them in new contexts. At this stage, the environment is skeptical of innovation and these innovators have a central role in spreading the idea Rogers (2003).

Following innovators, early applicants play a major role in the spread of innovation. They often hold leadership roles and act as advisors regarding innovation. Their attitude towards innovation is crucial as they act as a role model. The next sector that implements the new idea is the early majority. They apply innovation before the majority and have a significant role in its dissemination, through communication and networking (Rogers, 2003).

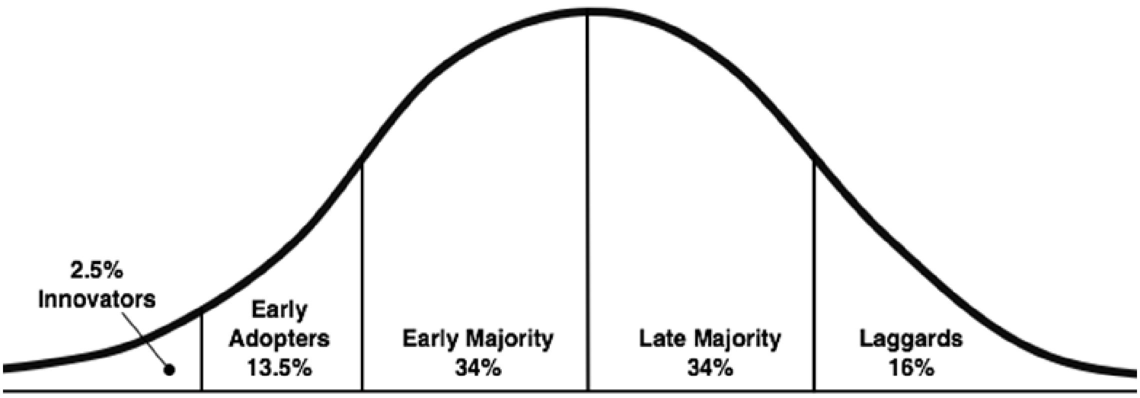


**Figure 2.5:** Adoption Curve (Rogers, 2003).

The late majority needs to be convinced about the innovation. They need to see the positive trend and that the uncertainties around it are gone. The last applicants are laggards. It takes a long time for them to decide on the innovation and be convinced of it. They often have a more limited network and limited resources, so they are less willing to take risks (Rogers, 2003).

The acceptance or resistance toward the use of a new technology depends on the individual perception about the benefits of this technology. It is important that innovation is perceived as a better solution than the existing one. New innovations must be accepted and considered useful by users in order to have an impact (Rogers, 2003).

It is important that it is perceived as a relative advantage of using a new technology over the existing solution it replaces and that it is perceived as easy to use. New innovations must be accepted and considered useful by users in order to have an impact. Many organizations are skeptical about implementing innovation that changes their working methods (Merschbrock and Rolfsen, 2016).

According to Rogers (2003), the level of spreading of innovation depends on five characteristics or qualities that are based on the perspective of the adopters:

- **Relative advantage:** The first sign is the relative benefit of innovation in comparison with the existing idea it replaces. The benefit is usually measured in economic terms, but it can also consist of factors such as comfort and social prestige. The biggest perception of advantage, the quickest the adoption is like to be.
- **Compatibility:** It defines the extension of which innovation is congruent or can be applied with the existing working methods or needs of the users.
- **Simplicity:** Those ideas that are simple to understand and do not require new skills are easier to spread. While ideas with a high degree of difficulty where users need to learn new and gain new knowledge would have a lower range of spread.
- **Testability:** Innovations that can be sampled to show the potential benefits and risks in advance are more likely to be implemented.
- **Observability:** The easier is for users to see the advantages of the new idea, the easier is for them to adopt it.

Training has an important role in the spread of innovation. Some authors claim that in order to increase the initiative a firm's tendency to innovate and get access to leading-edge knowledge it is crucial to continue training the workers (Bauernschuster et al., 2009; Dostie, 2018). Also, according to Dostie (2018), the second reported obstacle for innovation in Canadian firms is the lack of skill inside organizations. The training process could be conducted in classrooms as specific courses or on-the-job training. Both types of training have almost the same impact on the firms' initiative to innovate (Dostie, 2018). This means that any type of internal education, that is related to the field that is intended to innovate, has a positive impact on the firm's tendency to innovate.

Diversity has a positive impact on the ability of a company to innovate. Diverse teams inside organizations allow a broader search space where different competencies can challenge each other and knowledge can be combined. Organizations with a wide range of knowledge in different technologies have a better routine for solving problems or to deal with new challenges. However, the more diverse a team is, the better communication and interactions are required (Østergaard et al., 2011).

### 2.6.2 Unified Theory of Acceptance and Use of Technology

In order to obtain all the benefits that innovation could provide to a company, it is important that the employees accept and use innovation. According to Venkatesh et al. (2003), there are seven factors that have an impact on user acceptance and usage behavior towards innovation. Figure 2.6 shows the different factors and the relations between them. According to this theory, there are four factors that act as constructors of intentions or behavior drivers (Performance Expectancy, Effort Expectancy, Social Influence, and Facilitating Conditions). Gender, Age, Experience, and Voluntariness of Use act as moderators of the constructors' factors (Koral Gümüsoglu and Akay, 2017).

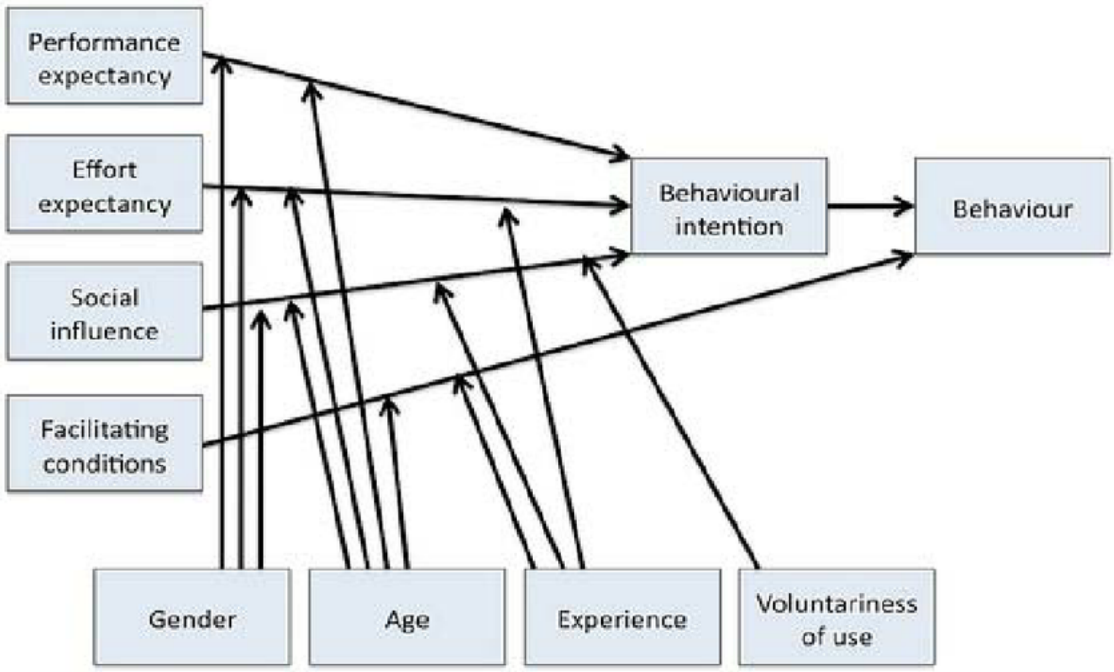


**Figure 2.6:** Unified Theory of Acceptance and Use of Technology research model (Venkatesh et al., 2003).

- **Performance Expectancy:** is the perception of an individual about the utility of a system to obtain an advantage or increase in job performance. This factor has the strongest influence on the prediction of use regardless of it is mandatory or voluntary. However, the relationship between performance expectancy and intention could be moderated by *gender* and *age* (Venkatesh et al., 2003).

  Age plays a moderating role. Young people give more importance to extrinsic rewards. This means that they are more willing to use and accept new systems that help them to increase their performance. According to Venkatesh et al. (2003), gender plays a similar role to age being men more task-oriented. However, as the author mention, the gender role is highly influenced by the socialization process and, for this reason, open to change.

- **Effort Expectancy:** refers to the perception of effort that would be required from an individual to use a new system. *Age* and *experience* act as moderators of this expectancy. Venkatesh et al. (2003) suggest that increased age and limited experience about a system increase the effort expectancy, reducing the intention of use.

- **Social Influence:** it refers to how the social perception of the use of new technology affects the individual willingness to use this technology. Experience act as the most influential factor decreasing the social influence while experience increase. Furthermore, social influence has a strong impact on mandatory uses of technology while this influence is reduced in cases of voluntary use.
- **Facilitating Conditions:** refers to how the employees perceive that the company has the conditions and facilities necessaries to successfully implement new technology. The influence of this factor could be moderated by age and experience. Being the old and experienced workers the one that gives more importance to the resources of the company (Venkatesh et al., 2003).

In order to increase the employees' willingness to implement new technology, it is important that companies provide the necessary resources and stress the importance of implementing it. Training programs play a key role in increasing performance expectancy by showing the benefits of technology. Furthermore, as education increase the skills of the workers, the effort expectancy is reduced. Also, as training is a company's initiative, it could increase the social influence and the facilitating conditions.

# 3. Method

A method by general definition is the used particular process for achieving a target or something specific. Many different ways to use in research method and each way could affect differently the study's results, where the most effective way will depend on the selected topic, the research purpose and the intended use of the results in additions to the researchers' assumptions.

Creswell and Creswell (2017) defines three main approaches for a method design to use in order to accomplish specific goals, qualitative, quantitative and mixed method approach. The distinction between qualitative and quantitative approach is framed in terms of the nature of the data itself. Soft data like using words, sentences, photos, and symbols dictate qualitative research strategies and data collection techniques rather than hard data inform of numbers for quantitative approach. Another difference between the two approaches is using closed-ended questions in the quantitative rather than open-ended questions for the qualitative interview questions. Whereas the mixed method approach is the integration of the two forms of data and using distinct designs that combine the two approaches (Creswell and Creswell, 2017).

The research method used in this thesis is a qualitative method based on a set of semi-structured interviews. Bellow the basic definition and the aim of the used approach will be presented.

## 3.1 Theoretical background of selected method

The aim of the qualitative approach is to understand and transfer specific research results done through visual perceptions or observations of people involved in the research. The qualitative approach is a way to explore and understand the meaning individuals or groups ascribe to the asocial or human problem. The approach process includes a set of activities as emerging questions and procedures, collecting data from participants, analyzing the collected data and making the data interpretation by researchers (Creswell and Creswell, 2017)

Neuman (2011) describes the qualitative approach as following a nonlinear path where there are fewer standardized procedures or explicit steps and researchers have to devise on the spot techniques for one case or study. Planning and design decisions are rarely separated into a distinct predate collection stage but continue to develop throughout early data collection (Neuman, 2011).

Many methods can be used during qualitative research such as interviews, observation, case study and record keeping. The Interview method can be personal interviews which carried out with one respondent at a time or a focus group interview which includes a limited number of respondents. Whereas in the observational method, the researcher checks the natural setting instead of relying on interviews and discussions, and that can be a last from a few days to a few years. (Reference needed)

## 3.2 Interview

The research interview has been considered as one of the most important qualitative data collection methods and been used widely in the conducting field study. The qualitative interviews may be used as a primary technique for the data collection or in conjunction with observation, document analysis, or other techniques (Hoepfl et al., 1997). These interviews have been sorted in a variety of ways. According to Patton (1990) there are three types of the qualitative interview; conversational interviews, semi-structured interview, and standardized interview (Patton, 1990).

Semi-structured interviews are most commonly used for qualitative research and can be conducted either with individual or in groups, these kinds of interviews are usually scheduled in advance at specific time and location. A list of predetermined open-ended questions is prepared to ensure the good use of the interview's time and to make the interview subject more systematic and comprehensive (Hoepfl et al., 1997).

In this thesis, the type of interviews is semi-structured interviews for different project's participants during the design phase. The interviewees represent both the client and the project contractors' teams. Interviews have been conducted with project members with different roles such as BIM coordinators, Design leaders, and VDC Specialists. The method was chosen because it is an excellent way to collect detailed information where it increases the opportunity for the interviewees to share their points of view and gives them the ability to express their opinions in a more flexible way comparing to other methods. Six interviews were performed in this thesis and all of them were done in English, each interview lasted between 45 minutes to one hour. The interview questions were structured as both main and sub-questions, the main questions were asked particularly to all interviewees whereas the sub-questions were asked to provide a clearer idea of a specific area or subject.

## 3.3 Ethics

The ethical issues are the concern, dilemmas, and conflicts that arise over the proper way to conduct research. Ethics defines what is not legitimate to do or what moral research procedures involve (Neuman, 2011).

The most important issue during writing this thesis was how to deal with the gathered data and information that been obtained during the interviews in an ethical way. During the interviews and writing the report of this thesis, many ethical principles have been taken into consideration to ensure the credibility way of performing the interviews, the correct way in dealing with data resources, to maintain the quality of information and to avoid mistakes during the report writing.

The interviews have been structured to provide answers to a specific area of interest. However, the interviewees were free to answer whatever they believe regarding the subject and based on their experience. All parties involved in the thesis were offered the chance to be anonymous the protection of their rights, and permission to record the interview was the main matter before the start of each interview. Moreover, the honesty in presenting the data and the interviewees' points of view in the report were important issues and any findings that questioned as confidential have been discussed with relevant people before being included in the report.

# 4. Findings

In this chapter the results of the interviews will be presented, starting with a presentation of the six interviewees followed by the results. Two different themes emerged during the analysis of the interviews and the results will be presented according to these themes; current use of BIM and 2D-Drawings. Both themes will be presented based on three perspectives; Designers, Contractors and Clients.

## 4.1 Presentation of the Interviewees

In this section a brief presentation of the six interviewees including knowledge background, work experience and their related to the thesis topic.

| **Interviewee** | **Position** | **Perspective** |
|---|---|---|
| Interviewee A | Design Leader | Design perspective |
| Interviewee B | BIM Coordinator | Design perspective |
| Interviewee C | Chief Information Officer (CIO) | Design perspective |
| Interviewee D | VDC Coordinator | Contractor perspective |
| Interviewee E | BIM and Cultural Heritage Specialist | Client perspective |
| Interviewee F | Design Coordinator | Design, contractor perspectives |

**Table 4.1:** Interviewee list.

- Interviewee A (IA): Electrical and mechanical engineering background. IA has been working in mechanical and HVAC (Heating, Ventilation and Air conditioning) sector for many years. IA current position is design leader for infrastructure projects. The knowledge IA has about BIM comes from the daily work activities by applying BIM as main work method for MEP (Mechanical, Electrical, Plumbing) design.
- Interviewee B (IB): Technical and design education. Work experience as both design coordinator and CAD manager for different projects. IA current position is BIM coordinator for infrastructure projects.
- Interviewee C (IC): Master of engineering in construction project management. IC has experience as 3D modeler. IC current position is VDC coordinator for construction projects.
- Interviewee D (ID): Technical and management educational background. ID has extensive experience in software development and solution architecture. ID current position is chief information officer (CIO) for infrastructure projects company.

- Interviewee E (IE): Architectural engineering background and master's degree in integrated conservation of built environment. IF previous experiences are: 3D designer, IT manager, BIM coordinator and BIM specialist. IF current position is BIM and Cultural heritage Specialist.
- Interviewee F (IF): Engineer with a broad experience working first as facility engineer for the pharmaceutical industry. Later, IF worked as a consultant for building sector. IF current position is design coordinator for offshore project in the Gas&Oil industry. The interviewee deal with BIM as a daily working method.

## 4.2 Current Use of BIM

### 4.2.1 Designers Perspective

The interviewees showed similar states of the use of BIM and a general definition of what they think BIM is. According to interviewee A, BIM is a tool for visualization and used to extract information about elements during the production and maintenance phases. What makes BIM a proper tool is the qualified people that use it. The technical knowledge, experience, and practical background are important to ensure the benefits of using BIM.

> *"..We can say BIM is like a hammer if you do not have the qualified person to use it, you won't get the results you expect.."*
>
> IA

The visual side of using BIM during the early stages of construction projects (tender and design phase) has absolute benefits, for large scale projects, BIM simplifies client requirements and makes them more understandable for the design team compared to the traditional way. Regarding the design phase, the 3D model and the communication between the design team are the two main points that the interviewee A believes are crucial. Involve the time planning and scheduling to the 3D model are still not that common. Even though the interviewee A thinks that 4D models increase the work efficiency of projects but most construction companies still prefer to use the traditional software that they have been work with such as *Primavera* or *MS Project*.

Interviewee B stated that BIM tools still have lack of functionality in handling projects' documents and that can be considered as the main obstacle in order to achieve the full potential of BIM. It makes people less willing to use BIM tools and search for different options.

> *"..Handling the management documents by BIM tools still need a lot of enhancement. BIM 360 for example, we can preview PDF files but we still cannot preview word documents.."*
>
> IB

For interviewee C the biggest impact of BIM technology for the productivity of the building sector would take place when BIM becomes more common during the Operation & Maintenance phase. The necessary resources during this phase are higher than during the rest of the phases. For this reason, any technology that improves productivity or reduces waste would have a great impact on the overall cost of a building. The next step of BIM technology should be the improvement of the BIM model, so the information contained on it become more accessible and useful for the O&M phase.

One of the present challenges of BIM technology is the lack of communication between different BIM tools. As formats are not yet standard and model information still project-based, it is difficult to create a database with all the information structured. As interviewee C believes that, the use of open-source formats and transparency in structure the information, as common information for all the industry, is the way to ensure the communication between different BIM tools without losing information.

The Gas&Oil industry has a different vision for the use of BIM compared to the construction industry. According to interviewee F, this industry put more effort into the design phase because of two main reasons. First, the offshore regulation is stricter and it is easier to check the fulfillment of those requirements on a BIM model. In addition, Gas&Oil clients are more aware of the benefits of having more detailed models for the Operation&Maintenance phase. The results from the design phase are more detailed models with big databases that can be used in maintenance software, interviewee F stated.

### 4.2.2 Contractor Perspective

According to interviewee D, BIM is a process to manage project information in order to improve the efficiency of different project phases (tendering, design, construction, and operation & maintenance). BIM models are considered as useful tools to use all over projects life-cycle. However, in order to use them, it is necessary to create them, and this is a process itself. To create a BIM model the first step is to have the client's requirements. These requirements have to be combined with the internal contractor expectation of the model used.

> *"..For BIM model we should have a version that meets the client expectation and the contractor requirements.."*
>
> ID

The relevance of BIM models has changed over time. In a traditional process, the main source of information and decision making are the 2D-drawings produced during the design phase. 3D models are created based on those 2D-drawings. The current way is to use BIM models as the main source of information, whereas 2D-Drawings are extracted from the models to be used as a support during the decision-making processes.

Interviewee D believes that the benefits of BIM technology are based on the project different phases. During the tendering phase, the visualization plays a key role by increasing the communication between client and contractor as well as making concepts and ideas more understandable. During the construction phase, BIM models improve works' preparations, simplify projects' logistics and enable earlier detection of conflicts.

One of the obstacles forward applying BIM on construction sites is how to provide projects' sites with sources such as telecommunication and the internet. In infrastructure projects such as tunnels, provide the internet could be considered as an issue to enable the construction team to use BIM models, interviewee D said.

the potential use of the BIM models is the link between the 3D models and the schedule of the project, creating a 4D model. In order to achieve this level of BIM technology, it is important that both contractors and designers possess the necessary skills to keep the model updated based on the schedule. This type of model could contribute to increasing the efficiency of project planning and logistics on site. However, the client usually requires the planning information of the project based on management software. For this reason, scheduling is made based on the clients' requirements

### 4.2.3 Client Perspective

As infrastructure projects in Sweden are governmental investments, the client representative for this type of project is the Swedish Transport Administration "Trafikverket".
According to interviewee E, BIM technology is a useful tool for some areas but it should not be implemented for everything. BIM technology is being a requirement by Trafikverket for all investment projects since 2015. However, BIM models are mainly used by the client in their 3D dimension: visualization, clash detection, and collaboration methods.

One of the future objectives of the client is the standardization of the BIM requirements and the information that should be included in it. Nowadays models and the included information are not linked to any database. For this reason, in parallel to the standardization of the information requirements, Trafikverket goal is to develop a database where all the information for BIM is stored and can be used in a more efficient way. However, one of the biggest challenges to achieve this goal is the different levels of BIM skills inside the organization. Some of the project leaders are still reluctant to use the BIM models on a bigger scale or do not have the knowledge to extract the necessary information from them.

Having a standard database information form projects would improve the Operation & Maintenance phase. Right now Trafikverket way to handle this phase is by recollecting projects' documentation and provide it to the maintenance contractor. The interviewee E mentioned that having more standardized information with a common structure in the early stages would improve this phase by avoiding the work replication.

According to interviewee E, the level of use of BIM models is still based on the decision of each project manager. Moreover, the included information in the model should be enough to run the project.

> *"..In each project, the level of information that should be included in the model should be at least as much as what the traditional documentation includes.."*
>
> IE

## 4.3 2D-Drawings

### 4.3.1 Designers Perspective

Reducing the production of 2D drawings from a designers perspective is a common goal that can be achieved in the near future.

According to interviewee A, 2D drawings' producing process consumes around 20-25% of the design phase time. The output of the design work process consists of three main deliveries: interdisciplinary check (IDC), issued of approval and approved for construction. In each submission, the design team has to deliver a 3D model and 2D drawings.

The interviewee A attributed the need for producing 2D drawings for two main reasons:

- The first one is the client requirements. As mentioned before, infrastructure projects are mainly governmental projects which belong to the Swedish Transport Administration "Trafikverket". The contractual forms in addition to the traditional way of implementing the projects by Trafikverket is still dominant, and mainly the demands for 2D drawings are the tradition.

  *"..The clients team is used to check 2D drawings to approve the design instead of checking the 3D model whereas they use 3D models more in the coordination meetings and to get more details.."*

  IA

- The second reason is due to the production works. The installation workers still have a lack of IT skills and knowledge to get what they need exactly from the 3D models. During construction phase workers can get either not enough information from the 3D models or too much information, more than they need. From a construction point of view, workers should get enough information to understand the installation. However, too much information could be counterproductive because it could confuse them.

Interviewee B claimed that right now it is possible to reduce the number of 2D drawings that are being produced. Drawings such as regular lay-outs can be easily removed and all information can be obtained from the BIM models. However, there are some documents such as technical schemes or process information that still difficult to be extracted from a BIM model and still needed to be in PDF format.

Interviewee A has recommended some solutions based on the current situation to enhance the use of BIM which could lead to eliminating 2D drawings:

1. Different interfaces of BIM models such as construction, engineering and maintenance interfaces where the users can find exactly the required information.
2. Enhance the way of dealing with new technologies by the client side "Trafikverket" is also a requirement to get more benefits of using BIM and reduce the waste.

For interviewee C the transition from 2D drawings to 3D models is perfectly possible. All necessary information for a specific project could be contained in a BIM model and extracted from it. The limitation of this transition is the difficulty of seeing the benefits of a full BIM industry in the long term. There is no strict actor that forces the industry to move forward. The current legislation still allows 2D drawings to be produced. The regulation should focus more on using 3D models instead of 2D drawings. It is a long-term investment that would not only improve the efficiency of the sector but also would have positive environmental effects.

> *"..It is important that the industry challenge the major software companies so BIM tools can be improved according to the necessities of the sector so the AEC industry could lead the process into a full BIM sector instead of just apply the given tools.."*
>
> IC

According to interviewee F, the design phase in the offshore project is similar to the building sector. The production of the 2D drawings could take up to 40% of the design phase and additional drawings could be produced during the construction phase. IF attributed the need for 2D drawings to the client approval regulation and the production phase. we deliver the requirements 2D drawings to the clients based on the project parts two weeks in advance, then we check the client's comments and go throw it on the 3D model with the client during coordination meetings. IF said.

### 4.3.2 Contractor Perspective

Interviewee D attribute the need for 2D drawing mainly because of the client requirements. 2D drawings are used for the client's internal review processes. Furthermore, 2D drawings are still required as contractual documents because BIM models are not commonly used as contractual forms by the clients.

During the design phase, 2D drawings are produced based on the BIM model, but after each revision process changes in models and drawings is mostly required, in that case, drawings should be produced again. In parallel to the revision process, there is an administrative process to handle all the documentation. All the PDFs need to be checked, send, and afterward, the revision has to be confirmed. These processes take a lot of time and can be avoided by only checking the BIM model, the interviewee D stated.

Moreover, interviewee D claimed that 2D drawings are still necessary because some details are inefficient to be presented in a 3D model so it is necessary to have them in 2D.

> *"...Some small details not possible to have them in a model, those small details are needed to be repeated many times in the 3D models so it is more efficient for the designer to have them in one 2D drawing instead.."*
>
> ID

One problem mentioned is that the level of knowledge about BIM is different inside the organization and between stakeholders. The construction industry is a relatively conservative sector. Professionals of this sector tend to work in a traditional way. Some people still prefer to work based on 2D drawings and use the 3D models as support. One thing that has to be taken into consideration is that, as right now there is a boom period of the construction industry. The schedules are very tight and it is hard to implement new ways of working, the interviewee D said.

The contractor is currently exploring the use of 2D views linked to the 3D model. It is a 2D view that just with a click on it could show the related 3D view. In addition, these 2D views can be printed in case of necessity. In this way, the formal 2D drawing production can be avoided. In order to implement this kind of solutions, it is important that all parties of the project are agreed with it and have the competences to deal with it.

Figure 4.1 shows two examples of this possible solution implemented by the contractor. This solution is based on the creation of 2D views in a .DXF or .DWF format. These views can be added into the coordination model and are directly linked to the model perspective. Right now this solution is been implemented based on Autodesk Naviswork.

The interviewee F believes that the use of 2D drawings during the production phase can be eliminated and if 2D drawings are not regulation requirements then there is no need to produce 2D drawings at all. On the other hand, IF thinks that the construction phase is not ready yet to use only 3D models because people are used to working with 2D drawings, and this change requires more time.

> *"..although I am a bit conservative for the traditional way of working, I think we can stop using 2D drawings because I see the benefits of the 3D models in the construction phase ..... I think my generation is not ready yet to use only 3D models.."*
>
> IF

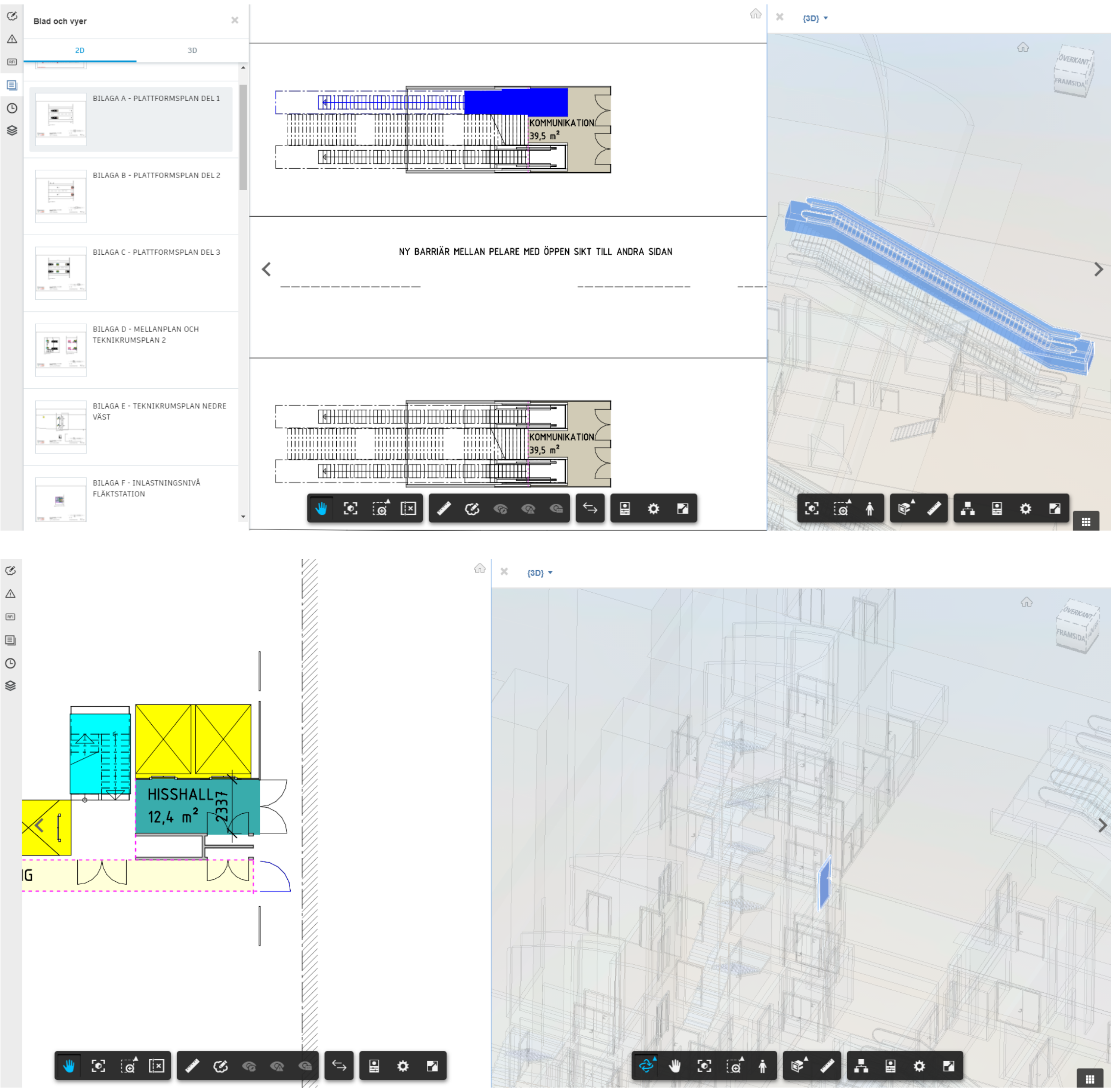


**Figure 4.1:** Example of the contractor possible solution.

### 4.3.3 Client Perspective

From a client perspective, the 2D drawings could be avoided. However, according to interviewee E, it requires an increase of knowledge from all the disciplines as well as an increase in the available information to understand and validate the project. On the other hand, interviewee E stated that there are several limitations that still restrict the application of the full potential of BIM:

- **Legal limitations.** Right now BIM models are not considered as a valid contractual document. The information contained in the models is limited and is not presented in a clear way. Furthermore, the documentation must be approved by the competent authorities (such as the different municipalities or environmental authorities) that still require 2D-drawings.
- **Review process:** Each project decides the extension of 2D-drawings that are required from the review process and internal management. There is a highly experienced workforce that prefer to work based on 2D-drawings for the review process.
- **Enhancement of the BIM tools** Get the information from the BIM model is not an easy process compare to extract it directly from the 2D drawings. The extraction of specific information such as dimensions or section details, comparing with the traditional method, requires more effort based on the available tools. For this reason, the enhancement of BIM tools is necessary.

# 5. Discussion

In this chapter, the theoretical background and the interviews' findings will be discussed. The authors' thoughts and reflections about the topic will also be presented in this chapter.

## 5.1 The current use of BIM

This study set out with the aim of assessing the importance of BIM technology in the Architecture, Engineering, and Construction industry. It is clear, from both the literature and findings sections that BIM has meant an important change in how the building sector develops its activities. However, the degree of extension and the impacts of BIM technology differ in real applications from what the literature states. All the interviewees agreed that there are lots of different benefits of using BIM in construction projects. Based on this fact, they stated that the construction industry can develop and become better, faster and more cost-efficient when using BIM more widely.

This means that in order to obtain those benefits it is crucial to make the whole industry aware of the benefits of using BIM and increase its use to higher levels. Based on the Diffusion of Innovation Theory by Rogers (2003), the current use of BIM as a visualization tool could be considered in the *"early majority"* stage (see section 2.6). Nowadays, Swedish organizations see the benefits of 3D models as a support tool and a way to improve collaboration in construction projects. BIM users at this level accept and consider BIM as a useful way to get better impacts in economic terms. Meanwhile, the acceptance of using full BIM as the main working method by Swedish organizations is still in the *"innovators"* stage. Construction companies are still skeptical in applying BIM and replace their own working methods with it.

### 5.1.1 BIM in the design phase

The design phase is the most important phase in terms of details and information that are going to be used in a construction project. This is the phase where BIM technology has had the biggest impact. There are many similarities between the attitudes expressed by the literature (Anderson O. and Zulfikar A., 2017; Eastman et al., 2011; Ghaffarianhoseini et al., 2017) and what has been described by the interviewees. In both cases, the main application of BIM technology is the 3D visualization of the building design, where the spatial correlation between different elements is better represented, allowing an improvement in the collaboration between different project participants. It is said that *"everything holds up on paper"*.

However, thanks to BIM models, design errors and risks can be detected in earlier stages, reducing their impact in the whole project.

During the design phase, all the available data for the project life-cycle should be included in BIM models. This process goes further the direct benefits for the design phase and the following stages would be affected by its outcome. According to the literature (Eastman et al., 2011; Weygant, 2011) it is possible to create BIM models that are digital copies of real buildings, with all the information regarding elements and, even with the textures and visual details (LOD 500). On this point, the results from the interviews differ depending on the perspective where most of the interviewees believe that it is not possible to create a BIM model with LOD 500 in an efficient way.

### 5.1.2 BIM in the construction phase

It is clear from the literature, that the application of BIM technology during the construction phase would lead to a waste reduction and an increase in productivity. The first and more direct benefit of BIM on construction sites is the use of 3D models as a visualization tool. This use allows a better understanding of the project's details, reducing the time that new workers or contractors require to be familiar with the project (Ghaffarianhoseini et al., 2017; Murvold et al., 2016; Simey, 2013). The results from the interviews further support this idea.

For the construction phase, one of the biggest advantages that BIM technology can provide is the improvement of work planning and logistics (4D models). As the included information in the model grows over and over the new projects, BIM models can be used as a database to schedule the material delivery or to plan the activities and logistics on site. In addition, when the contractor participates in the planning process and this information is included in the model, works can be planned in a more realistic way, decreasing waste and improving the efficiency of the construction phase. This benefit is mentioned in both literature and interviewees. However, while the literature assumes 4D models is something already implemented, interviewees claimed that, even if it is already possible to have 4D models and the benefits are clear, there is a long path left until it is commonly used in the AEC industry.

The findings from the interviews reveal that one of the problems for adopting BIM tools is the difficulty to bring, in an efficient way, BIM models into construction sites. Different solutions have been implemented in order to improve access to the information on site. On the literature based on previous projects, solutions such us BIM-stations or using tablets on site have been mentioned. However, according to both the literature (Brantitsa and Noberg, 2018; Merschbrock and Rolfsen, 2016) and the interviewees, these solutions are uncommon because there is still a lack of IT capabilities on the construction site. On the other hand, the interviewees highlighted that the on-site used software should be more suitable for site work. For this reason it is important that construction companies push software developers into the design of the applications based on the necessities of the ACE industry. Furthermore the telecommunication connections issues on site, especially in those related to infrastructure projects such as tunnels, need to be solved in order to deal with the level of data created on a BIM model.

In general there is a reluctance to implement new ways of working in the construction industry. The results from the interviews revealed that the main problem behind the adoption of the already existing BIM tools is the reticence of people to change their way of working. Several studies (Druver and Karlsson, 2018; Merschbrock and Rolfsen, 2016; Murvold et al., 2016; Simey, 2013) have highlighted that an important part of the manpower in construction projects is skeptical in the use of new techniques. In addition, it is interesting to note from the interviews' findings that the requirements from the client do not support or push forward the implementation of a higher level of BIM technology. Right now, the main contractual documentation, and the most used tool on construction sites are still the 2D drawings. It is necessary to mention here that the current requirements from the client side to choose a contractor, based on the lowest bid, could be considered as a real obstacle in order to help the change in the way of working.

## 5.2 2D Drawings

As mentioned before, 2D drawings are still an important tool and the only valid contractual form in construction projects. The results from the interviews are, in accordance with recent studies, indicating that right now most of 2D drawings are extracted from BIM models. This process takes around 20 to 30% of the design phase resources in order to produce this documentation. Furthermore, the administration process to handle all these documents makes the 2D drawings process in total represent around 40% of the design phase. Based on these results, the elimination of the use of 2D drawings could lead to an increase in the productivity of the design phase. In addition, in order to eliminate the 2D drawings, it would be necessary to increase the level of development on BIM models. According to the results, it would be necessary to increase the current time invested in the creation of BIM models in 10% in order to increase the LOD and include all the details presented in 2D drawings. In addition, the higher LOD of the BIM models would lead to an increase in the benefits of BIM all over projects life-cycle.

According to the literature about BIM, the technology is advanced enough to create BIM models with all the necessary information for a construction project, so 2D drawings, in terms of information are not necessary. However, the current use of BIM in the AEC industry is far from this stage. The reasons behind this as the results show, differ from one perspective to another. According to the designer and contractor perspectives, the use of 2D drawings can be, if not eliminated at least reduced to a significant degree. The problem is attributed to the client's requirements. The Interviewees from these two perspectives claimed that the client (Trafikverket) still prefers to work in their traditional way, using 2D drawings as main contractual documents and in the review process. This vision is shared in some extensions by the client. According to the client perspective, 2D drawings generally are still necessary because there is a lack of high competences about BIM technology. Moreover, the current legislation is not yet adapted to accept BIM models as a valid contractual document and most of the workforce still prefer to work with their traditional ways.

The results of this study indicate that the main factor behind the elimination of the need for 2D drawings is the attitude of the workforce towards the implementation of new ways of working. These results can be analyzed based on the theories of change (see section 2.6). Based on the Diffusion of Innovation Theory by Rogers (2003), the idea of removing 2D drawings is only implemented by *"innovators"* in some experimental projects (Merschbrock and Rolfsen, 2016; Simey, 2013). In general, the industry is really skeptical about the possibility of fully skip of 2D drawings. According to the results, there are always some drawings that are still necessary (such as principle schemes or detail drawings) that seem as indispensable.

The idea of increasing the use of BIM technology and, as a result, the elimination of 2D drawings has not a quick sepreading inside the AEC industry. One of the reasons is that this change is not just a change in technology but also in the way of working. The diffusion of this use of BIM technology clash against some of the characteristics that Rogers (2003) stated as drivers in the spreading of innovation:

- **Compatibility:** The use of BIM models instead of 2D drawings require a change on the way of working. This means that the employees, especially those how to have significant work experience, would not see it as a way of improving their work but a different way of doing it.
- **Simplicity:** In the case of BIM technology, it is necessary to learn new skills and to understand how the information is structured. The current BIM tools do not help to simplify this process. For this reason, it is not an easy process and, as a result, its spreading is more difficult.
- **Testeability:** One of the problems when it comes to applying new ideas in construction projects is the cost and complexity of it. The risk behind the implementation could be high due to the cost of each project. This means that it is not easy to test the real benefits of skipping the 2D drawings.
- **Observability:** The findings from this study suggest that in general, apart from reducing the invested time of creating and dealing with 2D drawings, there is not a clear advantage of skipping 2D drawings. From the design perspective, the main advantage is reducing the effort and, as a consequence, increase the productivity of the design phase. From the contractor perspective, there are two options depending on the type of contract. If a Design-Bid-Build contract is signed, for the contractor skipping 2D drawings would not represent any relative advantage in relation to the current situation of BIM. If the contract allows an early intervention of the contractor, the advantage of removing the 2D drawings would be also a reduction of paperwork. However, it would require adjustments on the construction site in order to improve the extraction of information from BIM models on site. Finally, for the client, an increase in the use of BIM would have advantages not only during the design and the construction phases but also during the Operation & Maintenance phase. The separation between the design and construction from the later

operation & maintenance phase of the same project and that leads to more difficult to see the advantages of investing in better BIM models and less 2D documentation. For this reason, the client is still reluctant to require a higher level of development in the BIM models.

The Operation & Maintenance phase of a building represents around 60 to 80% of the project cost (Akcamete et al., 2010; Nicał and Wodyński, 2016). This means that any change that could improve the productivity of this phase could have a great impact on the total cost of a construction project. Clients and administrations such as Trafikverket play a key role in the diffusion of BIM technology. Their requirements force the industry change in order to fulfil them. It is important that they see the potential of using BIM in a higher extension so they will increase the BIM requirements.

## 5.3 Diffusion of BIM technology

Based on the above sections (5.1 and 5.2) it is clear that the enhancement of BIM technology has a great effect on the current situation of the construction industry and a further enhancement will lead to a more efficient and sustainable way of implementing the construction projects. However, for achieving the full potential of this technology, the current barriers toward it should be overcome.

Nowadays, the majority of the AEC workforce has difficulties to accept and apply BIM during their daily base activities. In order to efficiently apply a new technology inside an organization, it is important that all the employees have the acceptance and willingness to use it. In that case, the required skills and information to handle it can be easily achieved.
According to the Unified Theory of Acceptance and Use of Technology by Venkatesh et al. (2003), four factors stand behind the acceptance of new technology by the employees inside an organization: performance and effort expectancy, social influence and facilitating conditions. For the employees, it is crucial to realize the benefits of new technology and how it could make their daily activities more efficient. On the other hand, the behaviour inside an organization toward a new method plays a great role to convince the employees to accept and deal with it. By showing the importance and value of embrace the new technology from the upper leaders, employees would accept its use easily. Furthermore, it is important that employees perceive that the organization is supporting and encouraging their learning and application process of the new method. For this reason, training programs would help not only to increase the general knowledge and advantages of applying BIM but also to perceive the importance of it.

Another barrier for implementing BIM in a more efficient way is the standardization process of the information. BIM models could contain a lot of information but, unless it is clear and well structured, people would be reluctant to use it as it will not represent an advantage. BIM technology provides with different tools but in different software. It is important to increase the use of open formats so the BIM models can be used all over the building life-cycle.

# 6. Conclusion

The purpose of the thesis is to investigate whether the production of 2D drawings can be dispensable and how this change in the design phase can affect the whole project life-cycle. The conclusion is based on the following three main questions:

### Is it possible to skip the production of 2D drawings process?

Right now, the production of 2D drawings cannot be totally skipped, but it can be reduced to over 90%. In general, the Swedish construction industry is not ready yet to such a change. The need for 2D drawings during the design and construction phases is still dominant. The domination of the 2D drawings could be mainly attributed to the current generation of leaders. BIM technology is considered as quite new technology and the top management positions in the construction sector are mainly occupied by a highly experienced workforce that relies more on their work experience and traditional methods of working. For this reason, any change in the work method will be a clash against what they consider as an efficient and useful way of working.

Moreover, the construction industry is still not aware of the full advantages of skipping the 2D drawings. By looking at this change as a change in the design and construction phases, the benefits of it are surely remarkable but still not very convincing for the construction companies to start applying it. The major impact of this change is during the projects' operation & maintenance phase, and the benefits of it during this phase should be the leading point toward it.

For this reason, in order to make the change possible, it is important to show the advantages of having better BIM models to the final client of a construction project. An example of this can be found in the Gas&Oil industry. In this sector, the clients do not hesitate to invest more resources during the design phase in order to obtain a highly detailed model that could lead to a more efficient operation & maintenance phase.

### Will this change lead to a more efficient design process?

Based on the current situation of the Swedish construction industry and in short term perspective and during the whole project life-cycle, it is more beneficial to produce 2D drawings even though during the design phase this process is considered as a waste of resources. Right now, in most of the cases, the design and construction phases are separated from the Operation & Maintenance phase and the as the main contractor is not responsible for this last phase, there are no incentives to create more detailed models and skip the 2D drawings.

A change in the perception of the usefulness of highly detailed models can lead to a more efficient design process. These models should contain enough information for the project implementation without the need for 2D drawings, and as the main way to extract the information for the operation & maintenance phase. So, from this perspective, project life cycle perspective, the production of 2D drawings will be considered as a waste of time and efforts and skipping it will lead to a more cost-efficient design process.

**How can this change in the design phase be implemented?**

During the design phase, the only impediment to skip the 2D drawings is the change of the working method by the design teams. The technical aspects to move toward this change can be solved, but change the people working methods is not an easy step. Understanding the new way will take time and showing the potential benefits of it will make the adaption of it easier and faster. A review of the clients' requirements and current regulations that governing the construction industry should be the main drivers of these changes. In order to do any change during the design phase, the clients' requirements should not be built upon the lowest cost as criteria to choose the designer. Trafikverket, as the main infrastructure projects client in the Swedish market, should consider the project life cycle cost as criteria instead of each phase cost. By analyzing each phase individually, the connections between phases are less clear and the impacts of increasing the investment in each over the others are overlooked. In general, from a designer perspective, being part of the discussion on pre-design stages could bring the possibility to convince the client about the potential of increasing the level of detail on BIM models.

In addition, the regulation forms should be changed in order to have BIM models as a valid contractual document. In that case, 2D drawing would not be necessary to formalize contracts.

The implementation of a design phase without 2D drawings would require raising the base knowledge about modelling from the design team. To do so, educational programs by the initiative of companies should be implemented. This could help the employees to see the advantages of using new technology, provide them with the resources to apply it in an efficient way and raise the general knowledge of the company. On the other hand, it is important to include in project teams new young people, less attached to the traditional methods and with a broad perspective about the BIM technology. This inclusion will lead to an information sharing process that could increase the positive perception about these new methods of the experienced workforce and, at the same time, the new generation will be trained.

## Suggestions for improvement

Considering the literature review and the interviews' findings, some suggestions that could help the implementation of BIM in the construction industry will be presented:

- **Following the neighbour countries:** Other Scandinavian countries have strong governmental initiatives with the objective of forcing the construction industry to use BIM technology to a higher extent. The Swedish construction industry could take the experience of these countries in order to apply those initiatives that have been proved effective.
- **Drive the standardization of BIM:** The definition of the concepts, rules, and regulation needs to be clear from all construction industry parties. BIM standards need to be set and driven by the whole society. The implementation of open source formats would lead to a more standard use of BIM, make the change possible for the industry as a whole.

## Future research

The research results showed some interesting issues that may be used in further studies:

- The first one could be the identification of the barrier behind the problem of using BIM models as valid contractual forms. If those problems can be solved the client could use BIM models in the reviewing and approval process of the project, reducing the need for 2D drawings.
- The second one could be a deeper analysis regarding the motivation factors behind the use of innovations and the development of a specific action plan to improve the diffusion of BIM technology throughout companies

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# Appendix A. Interview Questions

## General Questions

- What is your knowledge and experience of working with BIM?
- What do you think are the biggest benefits of the use of BIM? Biggest problems that its use implicate?
- In which extension is BIM used in your organization and in what stages.
- Do you think that the final result of the project could be improved by increasing the extension of the use of BIM?
- What are your expectations for BIM technology in the future?
- Do you think it is possible to reduce the 2D-Drawings (paper and digitally)?
- What type of 2D-Drawings cannot be replaced?
- What information is still presented in 2D-Drawings that cannot be found in BIM models?
- In what extent are necessary 2D-Drawings for the contractual documentation of the project? Could it be done based on BIM models?
- How does the contractual form affect the delivery documentation?
- Who is the biggest user of the 2D drawings throughout the project lifecycle?
- Who decides which 2D drawings have to be produced in the design phase?
- Have you been involved in a project where BIM 4D model was used?
  - If yes: any feedback from the project!
  - If no: why do you think it is still not common to link 3D models to construction activities?

## Additional Questions for Designers

- How do you use BIM and what is the most relevant information during different stages of the design phase?
- What is the LOD of the models depending on the stage of the project?
- How much time do you spend on producing 2D-drawings?
- What type of changes the design team usually do after each delivery stage?
- Do you have to produce additional drawings during the construction phase that haven't been specified?

## Additional Questions for Client “Trafikverket”

- What Trafikverket requires from contractors during the design phase? Mainly about 2D drawings.
- Based on the designer’s information: In order to approve the design models Trafikverket requires 3 main delivery documentations “3D models and 2D drawings” stages (30%, 60% and final delivery) why in each stage 2D drawings are required? Any purpose?
- What are the main obstacles from reducing the production of 2D-Drawings?
- What is the additional information that “Trafikverket” requires in the 2D-Drawings and not available in 3D models?
- Do you have any information about “Röforsbron” project (built entirely without drawing)? If yes: does Trafikverket use any concept from that project?
- What LOD “Trafikverket” ask for in this kind of projects and how does it use?

## Additional Questions for main contractor

- Any experience from a project where the traditional 2D-Drawings have been reduced or replaced by BIM models?
- How the use of 2D-Drawings can be reduced during the construction phase?
- What are the biggest challenges to use BIM models on the construction site?
- Do you work with a logistic 3D model?
  - If yes: how detailed is it, and has it contain schedule or time planning?
  - If no: why not? Do you think it could be a useful tool?
- What LOD do you expect on the BIM model from the designers and how is this information used during the construction phase?