DEGREE PROJECT

Augmented Construction

Developing a framework for implementing Building Information Modeling through Augmented Reality at construction sites

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Adam Carlsén & Oscar Elfstrand

Abstract

Construction projects struggle to meet their budgeted cost, time, and quality requirements due to problems with cross-functional communication, which are made worse due to usage of mediums that are unable to handle the increasingly complex information required in the projects. Visualizing Building Information Models (BIM) through Augmented Reality (AR) on construction sites is believed to have the potential to solve many of the construction industry's current communication problems. However, although academic efforts have been made regarding BIM through AR, contemporary research is limited to clinical trials and concludes that there is a need for studies conducted in real construction environments; even though practical testing has been conducted within the industry. To address this, the purpose of this report was to compile the academic knowledge and retrieve the experience available in the industry, and provide a situation assessment that updates the field of AR and BIM. Two research questions were formed: '*What are the opportunities of using BIM through AR at construction sites?*' and '*Which barriers are affecting the adoption of BIM and AR at construction sites, and what concrete measures can be taken?*'.

To answer the research questions, an exploratory study with abductive approach was used. The knowledge of industry practitioners with experience of BIM through AR testing, the usability of BIM, or the functionality of AR, was collected through 20 semi-structured interviews. These were analyzed using thematic methodology and the findings tested through a workshop at a major Swedish construction firm.

The result confirmed that BIM through AR can solve some of the current communication problems within construction, and several barriers affecting the adoption of AR and BIM were found. These could be categorized into the dimensions: *Process*, *User*, or *Technology*. To each barrier a corresponding measure was identified, for instance; anchor the use of AR and BIM strategically, have an active role in AR development, and create organic dispersion of the technology. The results are also visualized in a roadmap depicting the different steps towards fully implemented AR and BIM.

The findings contribute to the academia by extending the field of AR and BIM to include the perspectives of industry actors, and moving the focus of AR and BIM research past initial testing to actual implementation and usage of the technology. The main contribution towards managers is a roadmap which provides a sense of direction by being both a tool for assessing their company's position along the path of AR and BIM implementation, but also provides insight regarding how to progress to the next step towards achieving fully implemented AR and BIM.

Keywords: Augmented Reality; Building Information Modeling; Construction

Abbreviations

AR - Augmented Reality: The real word enhanced with digital objects

BIM - Building Information Modeling: Information process that involves the creation and management of digital representations of physical and functional characteristics of buildings

CAD - Computer Aided Design: Software that use vector-based graphics to depict objects

HMD - Head-Mounted Display: Wearable display for AR, usually a pair of glasses or a helmet

HHD - Handheld Device: Handheld device for AR applications, usually a tablet or smartphone

MR - Mixed Reality: The spectrum between the real world and Virtual Reality

VR - Virtual Reality: Digital environment where the user lack interaction with the real world

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1. INTRODUCTION

Digitalization is continuously changing the business landscape, and companies must transform their business models and operations to stay competitive (Fitzgerald, Kruschwitz, Bonnet & Welch, 2014). A steady influx of new digital technologies, combined with an increased usage and acceptance, presents opportunities for companies that are willing to adapt to the new paradigm and develop their processes (Grossman & Richards, 2017). Digitalization presents new possibilities in all industries, although the different industries' eagerness to transform and adopt these technologies is not evenly paced. A study by Manyika et al. (2015) showed that the most digitalized industry sectors consists of service-based businesses such as banking and finance, with advanced manufacturing not far behind. Meanwhile, the construction sector is among the least digitalized and ranks just above the agricultural industry. The Construction industry is an especially interesting case as even though being one of the least digitalized industries in the business landscape, it is also deemed to be among those that have the most to gain (Oxford Economics, 2015).

Accompanying the low degree of digitalization, Matthews, Love, Mewburn, Stobaus & Ramanayaka (2018) address that the construction industry has a reputation of poor quality, bad service, and a history of broken promises, which is consistent with previous works by both Egan (1998) and Wood, McDermott & Swan (2002). Furthermore, Abdul Rahman, Memon, Azis, Asmi & Abdullah (2013) in agreement with Frame (1997), specified that it seems to be the case that a significant portion of construction projects struggle in meeting the three basic criteria for project success; budgeted cost, projected time, and quality standards, as merely 16% of 8,000 construction projects satisfied these criteria. In a study of 258 construction projects, Flyvbjerg, Holm & Buhl (2003) found that the failure to meet these demands results in projects becoming increasingly more expensive, as nine out of ten projects faced cost overruns. Wikforss & Löfgren (2007), Kadefors (2004), and Bresnen & Marshall (2000) argue that these issues stem from a lack of cooperation, trust, and adversarial relationships between stakeholders, which can be traced to ineffective communication. Karrbom-Gustavsson & Gohary (2012) highlights that communication unfortunately has been taken for granted, despite that previous research by Dainty, Moore & Murray (2006) concluded that improved communication and collaboration is key to overcome ingrained functional boundaries and achieve improved performance in construction projects. More specifically, Svalestuen, Knotten, Lædre, Drevland & Lohne (2017) and Toyama (2006) emphasize that these issues are the result of a failure to engage in effective cross-functional communication and that the subsequent misunderstandings result in errors and high information transaction costs.

A reason for these cost-inducing misunderstandings is that the construction industry has to deal with complex communication processes (Ajam, Alshawi & Mezher, 2010) and increasingly complex information (Nguyen, Tran, Nguyen & Le-Hoai, 2016). This information is becoming harder to communicate through the traditional mediums, and Yeh, Tsai & Kang

(2012) highlights the inadequacy of 2D blueprints in constructions. Neff, Fiore-Silfvast & Dossick (2010) explain that architects currently create 3D models of the buildings, which are printed out as 2D drawings and distributed to the teams at the construction site. At each transfer of the building plans, the field team has to study and interpret the drawings to create a mental model of the intended 3D design. The authors state that since every receiver needs to make their own mental interpretation of the architectural representations; information from the original design intent is subsequently lost. As a result, Chi, Kang & Wang (2013) and Bernstein, Jones & Young (2008) argue that there exist an information gap between the planning and implementation stages of construction projects. Thus, there is a need for tools that better communicates the complex information required in construction.

A promising tool to enrich the communication in construction is Building Information Modeling (BIM), the potential of which has been acknowledged by scholars such as Azhar, Khalfan & Maqsood (2015) and Chen, Lu, Peng, Rowlinson & Huang (2015). BIM is a software tool for the construction industry that provides a digital representation of construction projects. But contrary to conventional Computer Aided Design (CAD), that represent the environment and objects with lines, arcs, circles etc., Azhar et al. (2015) adds that objects in BIM are defined as actual building elements such as beams, pipes, and trusses. The authors state that the models also can include data regarding suppliers, maintenance, cost, and timeframe and, thus, BIM can be seen as a process rather than just a software. According to Shen, Shen & Sun (2012), the introduction of BIM has enabled the flow of information and the communication to increase during the design phase, since the models can go from each department as they add their respective input; such as architecture, building services, and costing. In this aspect, BIM is a successful tool in the design phase, and according to Eastman, Eastman, Teicholz & Sacks (2011) the benefits include the elimination of most coordination errors, which can lead to reduced cycle times.

However, the usage of BIM currently ends at the design phase; thus, BIM in its current setting does not solve the information gap between design and construction. According to Svalestuen et al. (2017), BIM can open new communication channels between these departments, but this presupposes that the users can easily access the models during the construction phase. There have been studies conducted in order to move the models from the design phase to actual construction sites (Wang, Truijens, Hou, Wang & Zhou, 2014; Chu, Matthews & Love, 2018) and these showed that BIM can be advantageously used to support the construction workers in understanding the intended design. In academia the interest in BIM is growing, and the trend of BIM publications continues unabated with the range of subjects steadily increasing; among others regarding Augmented Reality (AR) and its potential to visualize BIM models (Volk, Stengel & Schultmann, 2014). Recent developments in AR have made it possible to utilize its visualization capabilities together with BIM, to bring the models from the design phase all the way to the construction site (Chi, Kang & Wang, 2013).

AR is described by Wang, Ong & Nee (2016) as an enhanced version of reality, created by visually overlaying digital objects onto the real world through equipment such as Handheld Devices (HHD), e.g. smartphones and tablets, or more recently Head Mounted Displays (HMD), e.g. glasses. Chi et al. (2013) add that the transition to HMD for AR provides the possibility of a hands-free communication tool that can convey complex information efficiently, and help bridge the information gap between design and construction. Wang & Dunston (2006) elaborate that AR is well suited for information-intense activities that currently rely on paper mediums for information retrieval, which makes the technology especially interesting for the construction industry as it is still heavily reliant on paper-based communication (Ajam et al., 2010). The relevance is also strengthened by Suk, Ford, Kang & Ahn (2017) who showed that the take-off performance when understanding 2D drawings are enhanced noticeably when combined with AR, as the geometrical understanding is improved. Furthermore, Hou, Wang, Bernold & Love (2013) found that AR can contribute to higher cognitive function and efficiency of assembly tasks. Through this attribute, Chu et al. (2018) argue that AR has been found to be a technology that can be used to enhance the process of extracting information from BIM models and bringing them to the construction site.

Although academic efforts have been made regarding BIM through AR, contemporary research by Chu et al. (2018) concludes that there is a need for studies conducted in real construction environments. This is supported by Jiao, Zhang, Li, Wang & Yang (2013) who argues that most existing research within the application of AR in the Architecture, Engineering and Construction sector is confined to lab prototypes. Chalhoub & Ayer (2018) agrees, and emphasize that there is not enough thorough knowledge regarding how AR might impact the construction performance of the industry practitioners. However, construction companies have conducted their own practical tests, but as of yet the experiences from these has not been transferred to the academia. Hence, *the purpose of this report is to compile the academic knowledge and retrieve the experience available in the industry, to provide a situation assessment that updates the field of AR and BIM.*

By combining the knowledge from both academia and industry the theoretical field of AR and BIM research will reflect the contemporary knowledge available in the industry, and in an effort to facilitate usage of AR and BIM, construction companies will be provided with concrete measures to overcome barriers hindering an implementation. Hence, the following Research Questions (RQ) was developed:

RQ1: What are the opportunities of using BIM through AR at construction sites?

RQ2: Which barriers are affecting the adoption of BIM and AR at construction sites, and what concrete measures can be taken?

This paper will focus on AR using HMD but information regarding HHD has still been included, however, it has entirely been used to support or strengthen information regarding HMD, and not to draw any standalone conclusions.

2. LITERATURE REVIEW

This chapter introduces key theories and concepts, and is a step to answer the Research Questions by founding a base that can be expanded during the primary data collection.

2.1 Construction, Cost, and Communication

The lifecycle of construction projects are generally divided into four phases; feasibility, design, construction, and operation (Zou, Zhang & Wang, 2007), see Figure 1. The feasibility phase involves the early stages of the project, e.g. ground surveying and requirement specifications. When a decision regarding investment has been made, the design phase is initiated, which involves the architect and engineering project functions. The construction phase is the actual production of the building and includes logistics, installations, building services, etc. this is subsequently followed by the operations phase in which the property manager is responsible for operating and maintaining the finished building.

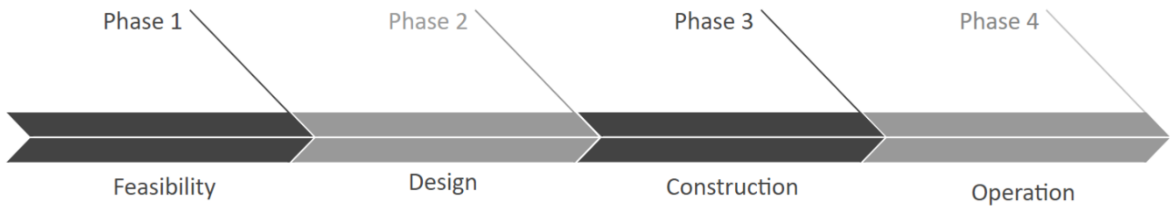

Figure 1: The four phases of construction, this report focus at the design- and construction phase

The importance of efficient and clear communication between different phases and departments can be traced down to the need to reduce costs, which can be explained through Transaction Cost Economics. According to Peng (2011), transaction costs are defined as the costs of all the information processing required to coordinate the work of people and machines that perform the primary processes of a company. The author notes that Transaction Cost Economics assumes an asymmetric distribution of information which means that people only have access to imperfect information, and information exchanges are therefore not costless. Furthermore, Toyama (2006) notes that this implies a fundamental relationship between transaction cost and different methods of communication, which is supported by Media Richness Theory.

Media Richness Theory was created to help organizations cope with unclear and conflicting messages by matching different media characteristics to certain tasks (Daft & Lengel, 1983). The theory differentiates between rich- and lean communication mediums and Dennis & Kinney (1998) argues that performance improves if rich media is used for communicating complex tasks, and vice versa. This means that different mediums have an inherent ability to communicate information, and by choosing the correct medium the effectiveness of the communication can be improved, which reduces the transaction cost. Svalestuen, Knotten, Lædre, Drevland & Lohne (2017) applied Media Richness Theory to the modern construction industry, and determined that BIM is a very rich communication medium that can enhance the communication between design and construction practitioners.

2.2 Building Information Modeling (BIM)

BIM Alliance (2017) defines four requirements that must be met in order to call a system BIM; the models must be object-oriented, the objects in the models must have certain properties, objects in the models have relations to each other, and different types of information can be viewed from the same model.

2.2.1 The business value of BIM

The power of BIM lies in its ability to represent all the information needed in a construction; such as cost, management, engineering, and architecture, in one centralized model instead of being fragmented in different applications, thus, if used correctly BIM can be present in the entirety of the project life-cycle (Bryde, Broquetas, & Volm, 2013). Chen, Lu, Peng, Rowlinson & Huang (2015) agrees that BIM is useful throughout construction projects, but adds that BIM models rarely reach the actual field teams at the construction site, which limit its capabilities. Grilo & Jardim-Goncalves (2010) adds that BIM is a progression to a more efficient construction process by allowing better communication of the building plans, as it is possible to add instructions, detect conflicting elements, and provide visualization, see Figure 2. Furthermore, the information in BIM models can be updated and changed easily which improves the information flow in the project.

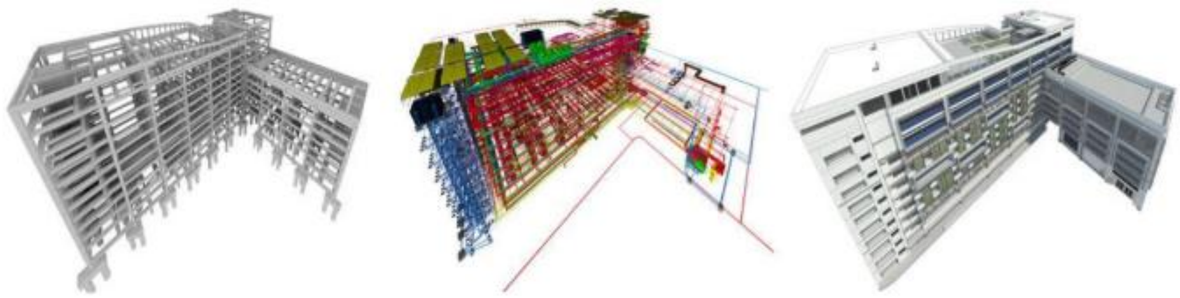

Figure 2: BIM models consist of different layers, such as engineering, HVAC, and architecture

The need for BIM grows from increasing complexity in construction projects as well as growing number of involved parties, which makes coordination and communication between project phases increasingly difficult (Bryde et al., 2013). New project management frameworks, such as Integrated Project Delivery, also increase the need for closer collaboration and more effective communication (Eastman, Eastman, Teicholz & Sacks, 2011). According to Hergunsel (2011), CAD and traditional drawings do not support the collaborative approach that the construction industry needs as both architects and engineers produce separate documents, and if the current progression in BIM continues, Azhar et al. (2015) predicts that BIM will completely replace CAD systems in construction. In a study of 35 construction projects, Bryde et al. (2013) were able to show that 60 percent of the cases reported positive results in cost saving as a result of BIM usage. Furthermore, 34 percent achieved time savings, 37 percent saw communication and information improvements, 34 percent improvements to project coordination, and 34 percent positive effects in quality.

2.2.2 Challenges with BIM

Although there are many benefits to be gained from using BIM, there are still challenges. Despite that authors such as Bryde et al. (2013) characterize BIM as being the most common denomination for a new way of approaching the design, construction, and maintenance of buildings; Bernstein & Jones (2012) saw that BIM usage in the construction industry unfortunately is not always obvious, as only 50% of American construction firms had access to BIM. Furthermore, there are several providers of BIM software and according to Azhar, Nadeem, Mok & Leung (2008) it is not certain that different software have full compatibility with one another. Gu & London (2010) agrees that this can be problematic if functionality disappears when companies, for instance, hire external consultants that use different versions.

Chen, Lu, Peng, Rowlinson & Huang (2015) argues that BIM is largely disconnected from the real-life physical building processes in current practice, and fear that BIM is at risk of being "blind and deaf" to ongoing construction processes. However, Chu, Matthews & Love (2018) bring up the risks associated with the amount of information contained in the BIM models and that if it is not managed correctly, construction workers can be exposed to information overload, that instead of facilitating their work may have a negative impact at performance and productivity. Bryde et al. (2013) add that negative experiences with BIM in most cases seem to relate to how the transition to BIM is managed and can be addressed with proper training and tools for the employees.

2.3 Augmented Reality (AR)

One of the more widely used definitions of AR is described by Azuma (1997), who defines AR as the superimposition of virtual objects upon, or composited with, the real world. In practice, this means that AR enables digital objects to be overlaid into our vision, and in doing so enhances the perception of reality. AR is a part of the broader concept of Mixed Reality (MR) which Milgram & Kishino (1994) describe as the spectrum of everything between the real environment; experienced without digital intervention, and Virtual Reality; a computer-generated environment where the user has no interaction with the real world, Figure 3.

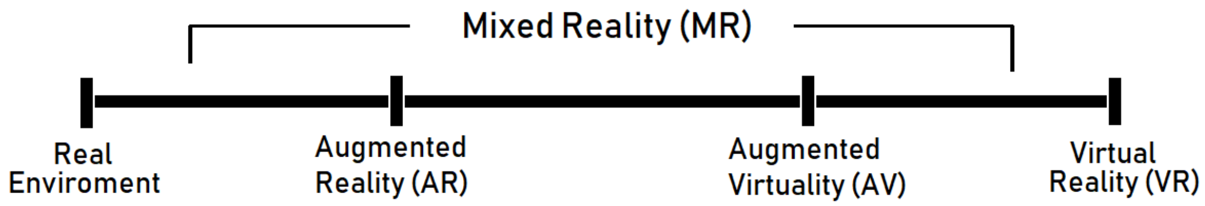

Figure 3: The Mixed Reality spectrum contains AR, but also other variations such as AV, that instead is a digital world enhanced with real objects

2.3.1 Displaying AR through Head Mounted Displays (HMD)

Zhou, Duh & Billinghurst (2008) divides HMD into Optical See-Through and Video See-Through. The authors explain that Optical See-Through HMD enables the user to see the natural surroundings with virtual overlays through their own eyes, whereas Video See-Through HMD relies on a screen to show the real environment as well as the virtual objects. Thus, Optical See-Through HMD provides a superior view of the real world and mostly seamless integration of virtual objects (Zhou et al., 2008).

In recent years there have been significant advances in the development of HMD, and there now exists wireless, lightweight, and stable versions which can be used for multidisciplinary purposes. Several tech giants and startups are working on their own set of HMD, for instance; Microsoft, ODG, and Daqri. According to Porter & Heppelmann (2017), there is a strong belief that it is only a matter of time before smart glasses will disrupt the market for tablets and smartphones and that screens eventually will be replaced by HMD. Therefore, the market for HMD is likely to grow significantly in the coming years. From being a technology that has seen a few specialized applications, AR is now believed to affect every industry in every sector and will change how enterprises make decisions, train employees, serves customers, create products, and manage value chains (Porter & Heppelmann, 2017).

2.3.2 The business value of AR

Tech giants such as Microsoft, Google, and Apple have put much faith in AR being the next big thing, and Alex Kipman of Microsoft stated that AR through HMD will be the eventual demise of the smartphone (Weinberger, 2017). While the prospect of HMD replacing smartphones and computer screens seems to be one of the more commonly mentioned traits of AR in the mainstream, experts within the field of business such as Porter & Heppelmann (2017) emphasize the technology's potential to enhance the ability to process and retrieve information. This sentiment is reinforced in literature reviews such as Mekni & Lemieux (2014), where a common theme regarding potential AR applications have a connection with the technology’s ability to relay information.

Porter & Heppelmann (2017) describe AR as the technology to bridge the gap between rich digital information and the physical reality in which it is used, and argue that AR enables a new information-delivery paradigm by allowing people to process both physical and digital information simultaneously, which eliminates the need to mentally translate two dimensional information into the three dimensional world. Porter & Heppelmann (2017) elaborate that this improves the ability to absorb and interpret information which leads to better decision making, and tasks being executed faster and more efficiently. By doing this, AR has the potential to address the issues in modern construction highlighted by Neff et al. (2010) regarding that the need to make mental 3D interpretations from 2D drawings results in loss of information. A study by Chu & Matthews (2018) contributes to this sentiment by arguing that AR ease information retrieval for people working in information-intensive environments, and increases the efficiency of the working processes through avoiding information overload. AR ability to effectively relay information enable the technology to be used for a variety of visualization and instruction applications, and Porter & Heppelmann (2017) believes that this allows AR to generate business value across the whole value chain through improved efficiency in companies' operations ranging from product development, manufacturing, logistics, and Human Resources. For this reason, the technology and its potential applications are being investigated by several industries, one of them being the construction industry which seeks to utilize AR for their current problems in communication and information sharing (Chi, Kang & Wang, 2013).

2.3.3 Challenges with AR

Previous studies with AR HMD have indicated certain challenges that need to be overcome to facilitate wider implementation of the technology. A study by Wu, Lee, Chang, & Liang (2013) underlined technological challenges such as the need for more well-designed interfaces and stable devices. This sentiment were emphasized by Li, Yi, Chi, Wang & Chan (2018) who claimed that the creation of more user-friendly interfaces to HMD is a significant challenge for the technology. Li et al. (2018) also points out challenges specific to the context of construction sites, where higher connectivity and interoperability between AR-systems and other Information and Communication Technology tools are needed.

2.4 Using AR to bring BIM to construction sites

The academic efforts regarding BIM and AR are directed to several areas along the building process. Despite being relatively scarce, the literature provides an overview of the possibilities, areas of application, and barriers. Early tests by Yeh, Tsai & Kang (2012) used an ordinary construction helmet with an integrated touch device and a small projector, which allowed information from BIM models to be projected at surfaces in front of the user. Although not directly using AR, the study constituted a strong starting point for more advanced technology. The tests provided significant evidence that dimensional information were better visualized and more intuitive than traditional drawings, and participants agreed that being able to interact with BIM is better than sifting through stacks of drawings. The test could also outline the need for more powerful hardware and integrated technology.

Wang, Love, Kim, Park, Sing & Hou (2013) took a theoretical approach and aimed to take BIM from design to real-time construction by developing a framework for integration with AR. The background was that the large quantities of information in BIM models, and how it is presented to the user, hinders the usability at constructions sites. AR was deemed as a feasible solution based on three main aspects; (1) The worker can receive information without being detached from the work, (2) AR lower the frequency of switching between information resource and work piece, and (3) AR displays information directly into the workers real world view, which is less straining on the heavily used short-term memory. Even though being excellent for visualizing information, it was discovered that AR needs to be context aware to provide relevant information. If so, AR was deemed to be a key enabler to address the shortcomings of the on-site use of BIM. Based on these results Wang, Truijens, Hou, Wang & Zhou (2014) conducted practical tests regarding how efficient AR would be to visualize BIM at a Liquefied Natural Gas plant, a highly complex construction project. AR was deemed feasible as it can merge the information and work activity, thus making the access of information more efficient. Both HHD and HMD was used as platforms for different activities; the HMD were used in hand-occupied activities as they have a significant advantage in this area. In agreement with earlier studies it was confirmed that BIM and AR need to be context aware to provide the proper amount of information; if the focus is on a detailed work piece, a detailed AR component should be shown, but a simpler model is needed for overall perspectives. A difficulty identified by the practical setting was that 3D modeling is often seen as an unnecessary complication by the practitioners, and that it is common to embrace the comfort zone and use tried and tested technologies, rather than adopt new solutions such as AR. Furthermore, a technical limitation was the lack of standardization among Information and Communication Technology.

Along with the process of using AR to take BIM to the construction site, Wang, Wang, Shou & Xu (2014) tested the capabilities of AR and BIM towards architects. The process of turning complex BIM models into 2D drawings removes much information, which leads to difficulties when the information is to be presented for owners. The authors created a system that was tested in four case studies with HHD, and the benefits proved to be improved visualization, communication, productivity, and reduced cost. Along with that, the users required high amounts of training and the authors could also specify several technical limitations that were previously not cited. These included that it was time-consuming to convert textures, lack of power in the rendering engine, GPS-based tracking and 3D tracking methods were not stable or sensitive enough, and the technology was in an overall prototype state.

One of the more recent contributors is Chu, Matthews & Love (2018) who evaluated how effective BIM and AR systems are for enhancing the information retrieval process in construction. The basis was that BIM models are rarely used on construction sites due to workers finding them less useful than 2D drawings; primarily as the information extraction from the BIM models requires larger mental effort. In agreement with previous studies it was shown that using BIM in combination with AR reduces the mental workload significantly, which improves information retrieval as well as reduces the number of construction mistakes. Furthermore, in line with previous notions regarding context awareness, the authors warned that BIM exposes workers with increasing amounts of information, which can hinder rather than improve productivity if not handled correctly.

2.5 Implementation of new technology

The transition from 2D drawing to BIM through AR will represent a significant change to the construction site, and to successfully conduct an implementation it is important to acknowledge the organizational implications (Matthew et al., 2018). However, according to Harty (2008), the models of describing innovation implementation does not account for the complex and dynamic reality within the construction process. The author explains that existing models of innovation implementation presuppose a controlled and homogenized implementation of new technology throughout an organization, but the construction process with its large number of actors and interwoven processes presents a reality where the technology will have widely different requirements of implementation depending where in the construction process it is implemented. As a result, it can be argued to be more valuable to discuss the general approaches of implementation rather than specific methods.

According to Sugarman (2001), implementation of change can be divided into two main categories, Push- respectively Grow models. The author explains that Push models are defined as when the process of change is conducted top-down in the organization, and is characterized by relying on strong innovation leaders to push the change through the organization by management authority. Matthews, Love, Mewburn, Stobaus & Ramanayaka (2018) add that Grow models instead focuses on a buildup of capacity to implement changes with a bottoms-up approach in which the employees are the facilitators of change, and their attitude, motivations, and visions are central aspects. Sugarman (2001) states that these categories have a history of limited success in organizational transformation on their own and therefore advocates a combination of these two approaches that pivots change through both strong and participating management as well as the engaged and intrinsically driven change of the employees. Vass & Gustavsson (2017) agrees that in the context BIM, a combination of these approaches will be fundamental to successfully implement and harness the true business value of BIM.

2.6 Summary of literature review

The findings in the literature review are summarized in Table 1 and structured under the appropriate Research Question (RQ). RQ1 could be divided into three dimensions, which in turn consists of different aspects. The first dimension, *Spatial cognition*, includes aspects regarding improved understanding and visualization of model content and a reduced number of mistakes. The second dimension was identified as *Increased Information flow,* which is related to the increased access to information and improved communication. The aspects that could not be grouped under the previous dimensions were grouped as a third dimension; *Other*. It is desirable that these aspects can be sorted under a more descriptive dimension after the primary data collection.

RQ2 could be divided into two dimensions; *Technology*, which consists of the technological issues affecting usage of AR and BIM, and *User* which consists of barriers related to the experience of the users. However, RQ2 aimed to identify both barriers to implementation and concrete measures that can be taken, but current literature mainly focused on describing the barriers, and not what can be done in practice to overcome these. Furthermore, general suggestions that by some authors were provided as solutions were regarded as barriers by others. Thus, these were not developed enough to be considered practical measures, and to fully answer RQ2 the practical measures need to be addressed in the empirical study.

Table 1: Dimensions, underlying aspects, and barriers relating to the Research Questions

Research Question 1: What are the opportunities of using BIM through AR at construction sites?		
Dimension	**Aspects**	**Authors**
Increased Spatial cognition	Improved understanding	(Chu, Matthews & Love, 2018), (Wang, Wang, Shou & Xu, 2014), (Wang, Love, Kim, Park, Sing & Hou, 2013)
	Improved visualization	(Wang, Wang, Shou & Xu, 2014), (Yeh, Tsai & Kang, 2012)
	Reduces the number of mistakes	(Chu, Matthews & Love, 2018)
Increased Information Flow	More efficient access to information	(Yeh, Tsai & Kang, 2012), (Wang, Truijens, Hou, Wang & Zhou, 2014), (Chu, Matthews & Love, 2018), (Wang, Love, Kim, Park, Sing & Hou, 2013)
	Improved communication	(Wang, Wang, Shou & Xu, 2014), (Svalestuen, Knotten, Lædre, Drevland & Lohne, 2017)
Other	Cost reductions	(Wang, Wang, Shou & Xu, 2014)
	Improved productivity	(Wang, Wang, Shou & Xu, 2014)
Research Question 2: Which barriers are affecting the adoption of BIM and AR at construction sites, and what concrete measures can be taken?		
Dimension	**Barriers**	**Authors**
Technology	Current AR devices are not powerful enough	(Wu, Lee, Chang, & Liang, 2013), (Yeh, Tsai & Kang, 2012), (Wang, Wang, Shou & Xu, 2014)
	Lack of well-designed AR interfaces	(Wu, Lee, Chang, & Liang, 2013), (Li, Yi, Chi, Wang & Chan, 2018)
	AR and BIM need to be context aware	(Wang, Truijens, Hou, Wang & Zhou, 2014), (Wang, Love, Kim, Park, Sing & Hou, 2013)
	Lack of interoperability between different hardware and software	(Li, Yi, Chi, Wang & Chan, 2018) (Azhar, Nadeem, Mok & Leung, 2008), (Gu & London, 2010)
	Lack of standardization in ICT tools	(Wang, Truijens, Hou, Wang & Zhou, 2014)
	GPS and 3D tracking must improve	(Wang, Wang, Shou & Xu, 2014)
User	Significant training and tools are needed	(Bryde et al., 2013), (Svalestuen et al., 2017), (Wang, Wang, Shou & Xu, 2014)
	Risk of information overload	(Chu, Matthews & Love, 2018)
	Resistance to change	(Wang, Truijens, Hou, Wang & Zhou, 2014)
	Requires engagement of the entire organization	(Vass & Gustavsson, 2017)

3. METHODOLOGY

This chapter describes the method and strategies used in this project to give an understanding of the process behind the results, and to enable the study to be replicated.

3.1 Research Approach & Strategy

The research used an abductive approach; a mixture of both inductive and deductive method. This was feasible as it according to Dubois & Gadde (2002) allowed for iteration between both empirical observations and theory. The authors explained that the abductive approach is suitable for research which main focus is related to generating new concepts and models. Thus, rather than confirming existing theory the abductive method is used to expand current literature, which this thesis aimed to achieve. Furthermore, the literature regarding the subject is relatively scarce which makes the nature of the research exploratory. Explorative research is according to Saunders, Lewis, & Thornhill (2016) particularly useful for clarifying and understanding issues, problems or phenomena, and was well suited for explaining the issue of practically implementing an AR and BIM combination at construction sites. An explorative methodology has the advantage of being highly adaptable and flexible to change (Saunders et al., 2016), which is advantageous since the factors causing this topical issue are unclear. The primary data largely consisted of input from in-depth interviews with industry professionals, which gave the research a qualitative research approach (Saunders et al., 2016). Finally, the research implemented a multiple case study strategy; both Dubois & Gadde (2002) and Saunders et al. (2016) agrees that this research strategy has the capacity to generate insights and in-depth understanding of a phenomenon within its real-life context. This leads to rich empirical descriptions and theory development, which current literature is lacking.

3.2 Case Selection

Cases were chosen based on a selective selection, thus, initially based on the authors' own knowledge of the subject and perception regarding whom should be examined. This was done by searching AR and BIM projects, and news articles for key actors. New cases were successively found using the snowball effect, where respondents gave leads to other relevant actors. Four categories of actors were identified; *(1) Users*, which included large construction companies active in Sweden with more than 2,000 employees, that either conduct- or are planning tests with AR and BIM at the construction sites. These were considered a representative sample as they constitute a significant part of the total sector and have the ability to test the technology in major projects. *(2) Supporting actors*, consisted of companies supplying construction companies with consultancy and services *(3) Hardware developers*, consisted of companies that provide AR hardware, and *(4) Software developers* provide software especially for merging AR and BIM. Table 2 depicts an overview of the cases.

Table 2: The examined cases and their respective description

	Type of organization	Description
Users	A: Large construction company	Major Nordic construction company, investigating the possibilities of AR and BIM
	B: Large construction company	Major Nordic construction company testing AR and BIM
	C: Large construction company	Major international construction company testing AR and BIM
	D: Large construction company	Major Nordic construction company testing AR and BIM
Supporting actors	E: Professional services firm	Major international consultant company with experience of BIM and AR
	F: Trade association	Swedish trade association advocating expanded usage of BIM
	G: Architectural firm	Swedish architectural firm with experience of BIM
Hardware developers	H: AR hardware developer	Swedish developer of AR glasses for industrial applications
	I: AR hardware developer	Swedish developer of AR glasses for industrial applications
	J: AR hardware developer	Swedish developer of AR hardware specifically for the construction industry
	K: AR hardware and software developer	Major international hardware/software developer producing market leading AR HMD
Software developers	L: AR software developer	Swedish company developing AR Software developer for construction firms
	M: BIM software developer	Company specializing in creating accurate BIM models of existing products

3.3 Data collection

The research consisted of both literature and primary data. The literature was used as a foundation for the primary data as to make sure the research was well founded in academia, which the primary data could confirm and expand upon. As the subject is quite preliminary and the technological availability is changing, all data had to be interpreted accordingly as the surrounding circumstances changes from year to year. It would have been desirable to exclusively use completely contemporary data, however, this would simply reduce the supply too much, and the data was instead used in a manner that emphasized newer information.

3.3.1 Literature

The literature is composed mainly of peer-reviewed articles, but also books and recent industry reports. When searching for literature, the titles of the results were audited to confirm their relevance, if so, the abstracts were read and the article skimmed through. When the relevance was confirmed a thorough read-through was conducted, finally, the list of references was monitored to detect further research. The databases that have been used is Luleå University Library, Science Direct, Scopus, and Emerald Insight which were primarily searched according to the keywords: *Building Information Modeling, Augmented Reality; AR in construction; BIM and AR; integrating BIM and AR; Communication in construction; Digitalization in construction; BIM at the construction site.*

3.3.2 Primary data

The primary data consisted of interviews with personnel at each of the cases. All interviews were recorded and transcribed to ensure that no details were overlooked, and both authors were present to assure a consistent format. For a detailed description of the interviewing process see *Appendix 1 - Empirical Process.* The interview guides were modified depending on the role of the respondent and revised between interviews; the final versions can be seen in *Appendix 2 - Interview Guides*. Table 3 depicts an overview of the interviewees. All interviews were conducted in Swedish, hence, the quotes in Chapter 4 have been translated, and the original quotes can be found in *Appendix 3 - Original Quotes*.

Table 3: Description of the interviews and the interviewees

Resp.	Name	Organization	Interview	Date	Length (min)
R1	BIM Manager	D: Large construction company	Video call	18-02-27	65
R2	Rock mechanics Engineer	E: Professional services firm	Voice call	18-02-28	40
R3	Visual artist and Urban planner	E: Professional services firm	Voice call	18-02-28	38
R4	BIM Strategist	A: Large construction company	Face-to-Face	18-03-01	68
R5	BIM Developer	B: Large construction company	Voice call	18-03-02	34
R6	Solution Specialist	M: BIM software developer	Voice call	18-03-05	44
R7	Digital development Coordinator	A: Large construction company	Face-to-Face	18-03-07	64
R8	Head of Logistics	A: Large construction company	Face-to-Face	18-03-09	60
R9	Project manager Logistics	A: Large construction company	Face-to-Face	18-03-15	55
R10	CAD / BIM Specialist	C: Large construction company	Voice call	18-03-20	76
R11	Technical Expert	F: Trade Association	Voice call	18-04-10	45
R12	CEO	J: AR hardware developer	Face-to-Face	18-04-12	53
R13	Key Account Manager	H: AR hardware developer	Voice call	18-04-13	56
R14	Owner	L: AR software developer	Voice call	18-04-18	62
R15	Architect / BIM Specialist	G: Architectural firm	Face-to-Face	18-04-19	41
R16	Architect	G: Architectural firm	Face-to-Face	18-04-19	59
R17	Head of IT	G: Architectural firm	Face-to-Face	18-04-19	25
R18	Technology Specialist	K: AR hardware and software developer	Video call	18-04-20	62
R19	BIM Coordinator	A: Large construction company	Face-to-Face	18-04-24	60
R20	CEO	I: AR hardware developer	Voice call	18-05-04	30

20 interviews were conducted for a total of 1037 minutes. The interviews were of a semi-structured format to ensure that the discussion remained topical but simultaneously enabled further exploration of the respondents' answers (Saunders et al., 2016), therefore, the questions were of a reflective and in-depth nature. This necessitates the establishment of trust and rapport to avoid response bias which is best achieved through face-to-face interviewing (Saunders et al., 2016). However, in some cases, the geographical location of the interviewee made video- or phone interviews necessary.

3.3.3 Workshops

A 106 minutes long workshop was held to confirm the results from a practical standpoint, and compile these to a format that is useful in an industry setting. The workshop was a step in a pursuit for balance between the theoretical and practical relevance. It was held at a major construction company in Sweden with three employees from the operational development department as they represent a part of the potential users, and possess knowledge regarding implementation of new technologies in the construction industry. The participants were presented the findings and were asked to discuss the relevancy and usability. Several ideas were raised regarding how the result was presented and a more visual approach was requested. Factors were then grouped based on relevance and rational order of implementation to build several steps in the process of bringing BIM though AR to the construction site. To pilot the workshop a guide was made, see *Appendix 4 - Workshop Guide*. A week after the workshop a follow-up meeting was held to discuss the result.

3.4 Data analysis methodology

The data was analyzed throughout the collection process with the use of thematic methodology. Thematic methodology is used to recognize, examine, and distinguish patterns within data through the use of coding, and is a commonly used method in qualitative studies (Braun & Clarke, 2006). The methodology has the strengths of being both systematic and flexible; it is systematic by providing organized and logical ways to analyze qualitative data and flexible in the sense that it can be used irrespectively to both research philosophy and research approach (Saunders et al., 2016). In other words, it is not restricted to either an inductive or deductive approach and was well suited for a combination of the two, e.g. the abductive approach in this report. Therefore, the thematic approach was appropriate since it provided a systematic analysis of data patterns and facilitated the abductive research. The analysis was conducted by using the six phases described by Braun & Clarke (2006):

1. Familiarizing with data
2. Generating initial codes
3. Searching for themes
4. Reviewing themes
5. Defining and naming themes
6. Final analysis and report

Phase one involved the transcription of the interview recordings, which was done immediately after each interview. This was followed by the reading and re-reading of the transcripts to increase the familiarization with the data. During the first phase, the search for meanings and patterns in the data was initiated together with preliminary ideas for codes. This was followed by the **second phase** which included the actual coding as well as organizing the data into meaningful groups. When all data had been coded the **third phase** focused on a wider level of examination were the codes were analyzed for underlying themes and categorized into main themes and subthemes, see *Appendix 5 - Representative quotes and underlying themes*. The **fourth phase** consisted of reviewing whether these themes described the coded data set in an accurate way and searched for relationships among themes. In **phase five and six** the identified themes were further refined, and the final analysis was conducted which consisted of descriptions and arguments for how the identified patterns could be used to answer the research questions.

3.5 Quality improvement measures

The goal of the research was not only to fulfill the research purpose, but also to do so in a trustworthy manner, which in qualitative research is done by ensuring *credibility, transferability, dependability,* and *confirmability* (Lincoln & Guba, 1985). The relation between this report and the four criteria was as follows: the **credibility** was improved by using triangulation which was achieved by gathering information from both literature and primary sources, but also confirming the result by utilizing workshops. The credibility was improved over four seminars where the report was critically screened by other writers of master theses. Finally, the report was peer-reviewed by a course supervisor before publication. The **confirmability** was augmented by having both authors present at all interviews and the workshop, and bias among different actors was reduced by including different cases that have different roles in the process of bringing BIM and AR to the building site. **Transferability** was ensured by always keeping the context surrounding statements made in interviews and articles, thus, even though two answers were categorized in the same category, the overall context surrounding the answer was included. Finally, to improve the **dependability**, the choices made regarding the method, theories, and interviews have been motivated in this chapter.

4. FINDINGS

This section presents the findings from the interviews and consists of two chapters. Chapter 4.1 focuses at Research Question 1: *What are the opportunities of using BIM through AR at construction sites?* Chapter 4.2 target Research Question 2: *Which barriers are affecting the adoption of BIM and AR at construction sites, and what concrete measures can be taken?* In conjunction with each chapter a framework illustrate the findings.

4.1 Opportunities of BIM & AR at construction sites

The primary data regarding the opportunities of BIM and AR at construction sites confirmed the relevance of the previously identified dimensions *Increased Spatial Cognition* and *Increased Information Flow*, with the addition of a previously unmentioned dimension; *Emancipated Resources*, Table 4. The previously uncategorized aspects 'Cost reductions' and 'Improved productivity' could be placed under the new dimension.

Table 4: Overview of the empirical findings regarding Research Question 1

Dimension	Description
Increased Spatial Cognition	Creates a shared view of the construction project which leads to better understanding of design intent, increased coordination, and reduction of mistakes
Increased Information Flow	Gives workers access to centralized and up to date information which eases the communication process, provides increased means of process efficiency, and enables a proactive approach to problem solving
Emancipated Resources	Frees resources by reducing administration, costs, and increased efficiency of the design process

4.1.1 Increased Spatial Cognition

In agreement with authors such as Chu et al. (2018), a prevalent opinion among the respondents was that one of AR and BIM greatest contributions is increased spatial cognition, i.e. the ability to understand geometries and shapes. The interviews confirmed that this is improved compared to 2D drawings, and a 'BIM manager' who had tested AR and BIM at construction sites expressed acclaim:

> *"When explaining how something should look like, it doesn't get better than doing it with AR"* (R1)

The core value of increased spatial cognition is giving the practitioner better understanding of the design intent, which reduces the number of construction mistakes. The 'Solution Specialist' at a BIM software developer describes the current difficulties in creating a shared view in projects:

> *"Imagine coming to the site and the first thing you need to do is to read up on the drawings, good luck getting a clear understanding of the project, goals, and what is expected of you with the help of that! Everyone make their own interpretations"* (R6)

Improvement in spatial cognition can result in that parts of the time spent at coordinating, instead get allocated to construction.

4.1.2 Increased information flow

In conjunction with authors such as Svalestuen et al. (2017), the interviews supported that bringing BIM to the construction site allows for increased information flow. A 'BIM Strategist' describes this as the main reason that BIM through AR is tested:

> *"The background to why we are doing this is that the construction industry consists of many actors with many people who all must send information to each other"* (R1)

AR will enable the construction workers to use centralized information which ensures that it is up to date. A 'CAD/BIM Specialist' underlined the importance of up-to-date information, but explained that this is problematic when working with traditional drawings:

> *". . .as soon as you collect the drawings from the drawing table they are outdated as a new version has already been released, that's the reality"* (R10)

Several respondents agreed, and a 'BIM Strategist' raised another perspective regarding the value of increased information flow, by adding that it can shift the industry from its current passive problem solving to an active approach:

> *"When you have information flowing throughout the process from the same model; then you effectivize on a whole other level than simply looking for existing errors"* (R4)

This was supported by the 'owner' of an AR software company who highlighted that since AR hardware is equipped with several cameras and sensors; it can collect large amounts of data from different processes. This feedback is valuable from a process development perspective:

> *". . .this gives us intelligence about everything from planning the logistics of delivering concrete to seeing what methods of inserting rebar's is the most efficient for different types of elements"* (R14)

4.1.3 Emancipated Resources

The current building process relies heavily on paper-based communication and traditional drawings entail unnecessary costs due to administration. Construction workers have a history of being handed many different duties, apart from actual construction. One example is logistics that is only recently being centralized, which free lots of resources. The same should go for making sure that the latest drawings are available:

> *"We also put in a lot of work administrating paper due to changes and revisions of drawings because everything has to be moved and sorted manually, this doesn't create value for the customer"* (R7)

The amount of work in the design stage will also be reduced if 3D models reach the construction site. Currently, both 3D models and 2D drawings are made as the model does not replace the drawings. While not conveyed in contemporary literature, a 'rock mechanics engineer' that was part of a project without 2D drawings explained:

> *"We always wanted to move in this direction because the coordination process gets much easier when everything is in 3D. We had done it to some extent before, but we had to stupidize the 3D models by making 2D cuts, which implied additional work that we now are getting rid of"* (R2)

4.2 Barriers and concrete measures for implementing AR and BIM

Before reaping the benefits of BIM through AR there are barriers that need to be overcome. The literature raised two dimensions; *User* and *Technology*, and the empirical data collection could confirm their relevance. The same goes for a majority of the corresponding barriers identified in the academia, with the exception of: 'Lack of interoperability between different hardware and software', 'Lack of standardization in ICT tools' and 'Significant training and tools are needed'. These were therefore excluded. Contrary to literature, the interviews provided concrete measures to overcome the barriers.

The interviews also revealed that there is an additional dimension of barriers identified as *Process*. This dimension is related to the comprehensive soft factors affecting business and process development, such as the organizational policies or ways of working in the construction industry. Table 5 provides an overview; but to receive background and context, the corresponding paragraph in this chapter should be read.

Table 5: An overview of the empirical findings addressing Research Question 2

Dimensions	Barriers	Concrete measures	
Process	Inadequate sharing of knowledge	**Internal cooperation**	Establish AR/BIM program to coordinate development and knowledge sharing
		External cooperation	Industry wide knowledge exchange
	Low understanding of potential applications	**Conduct pilot tests**	Test and benchmark against current processes, and showcase the results
	Tests are confined to technical evaluations	**Anchor AR in vision/strategy**	Involve AR and BIM in a strategy, and formulate clear goals and milestones
	Lack of resources to develop process	**Allocate staff**	Ensure that sufficient resources, staff, and competence are given to projects
	The approach to BIM	**Raise the status of BIM**	Make BIM the legal building document
		Develop Model Maturity Index	Standardize model handling and level of detail requirements for different phases in the building process
Technology	GPS and 3D tracking must improve	**Improved positioning technology**	Investigate the possibilities of combining satellite navigation with 5G
	Current AR devices are not powerful enough	**Simplify the models**	Simplify models without reducing the usability in different processes
		Cloud computing	Utilize data streaming to overcome lacking processing power of AR
	Lack of well-designed AR interfaces	**Active role in development**	Dialogue between construction actors and AR developers

User	Resistance to change	**Organic dispersion of technology**	Ensure that user engagement is the driving force of the dispersion of AR and BIM to new areas. Support this from management by encouragement and resources
	Requires engagement of the entire organization		
	Risk of information overload	**Develop for a specific area**	Focus AR and BIM development at creating solutions with high usability for specific areas before expanding
	AR and BIM need to be context aware		

4.2.1 Process

Internal cooperation. An over-the-wall approach to communication in the construction industry makes the internal communication inadequate, which results in inefficient use of resources and a slow pace of development as different parties at different locations examines the same things. This calls for increased coordination and internal communication in the management of the different AR projects:

> "*. . .the companies are very compartmentalized and people don't communicate; there are employees who buy AR hardware and then there's someone else doing the same thing within the same organization, but they don't know about each other"* (R12)

A 'Digital Development Coordinator' at a major construction company explained that in a worst-case scenario the lack of coordination and internal communication causes persons or departments to obtain certain technology without the proper support and infrastructure of the organization as a whole. This leads to test projects which do not generate any results:

> *"Many has lost their trust to the strategic development and instead run their own race, but they run into dead-ends in the development when they realize how much is required to take it to the next level as there's no dedicated time for this"* (R7)

To overcome these problems, a dedicated AR program should be created so that the same problems or technology is not evaluated over and over, and the available knowledge is centralized instead of being spread out among individuals. A respondent who had been part in the creation of such program said:

> *"It's not uncommon that we sit and work with similar things in different countries and that we share the same challenges. In those cases it's good to have a sounding board were we can share experiences with each other, which is why we created an international network so we can advance faster"* (R5)

External cooperation. The whole industry faces similar challenges for implementing AR and BIM, and by initiating cross-industry cooperation within the area, the knowledge and development would advance. It is arguable that one could get a competitive advantage by not sharing certain progress, but respondents suggested that there is more to gain by dividing the efforts. A 'CAD/BIM Specialist', who conducted test with AR in construction, expressed the following:

". . .we need to start seeing each other more as allies than competitors when it comes to digitalization, we compete in the core business not in digitalization. We need to learn to think in this manner and not see this as another area of competition" (R10)

Cooperation will only be possible if all parties experience benefits. One of the main arguments is that attention and negotiating power in the dialogue with AR developers will increase. A respondent who was part of early BIM through AR testing saw this first hand, and argued that a coordinated approach to industry cooperation could generate even more substantial benefits:

"We should look into an industry wide initiative where we, through 'IQ Samhällsbyggnad' [trade organization] or some other actor, together outline requirements for what we need. This would give us a completely new forum with which we can reach out to hardware developers" (R14)

Cross-industry cooperation is also a factor of pure necessity. This was apparent as respondents raised concerns that passiveness opens up the market for new competitors that can build their business model around the available technology:

"It doesn't look to well for a lot of construction companies, and this has nothing to do with the housing market. Take Carillion that recently went bankrupt as an example; 35,000 employees and they fell all the same. In its' place, new companies that see the value of the new technology will emerge" (R6)

The probability that new actors get a grip at the market increases drastically if the industry does not seize the opportunity to jointly develop.

Conduct pilot tests. '*You learn as you do*' was common expression among the respondents who had conducted testing. No one claimed to have found the absolute way to use either AR or BIM at construction sites, but underlined that testing had been essential for understanding how the technology can be used and what needs to be developed:

"*. . .the pilot is an instrument to move forward, the technology is new but the ways of working and legal aspects will also need to be revised"* (R14)

So instead of expecting everything associated with AR to performance flawlessly, testers instead exploited what worked well and took the technology as far as possible:

"It's by already pushing some projects really far that we can help both the client and provider to understand what requirements they need to set up for the next" (R14)

Thus, the pilot is a way to ensure that solutions are developed and exist in the future.

Anchor AR in vision/strategy. Another benefit of pilot testing is to create common goals for how the technology should be used in the organization, so that AR and BIM can be anchored in a vision and later be developed into a strategy. The strategy enables companies to break down the implementation into concrete milestones, which makes it more manageable to create the settings to support the new ways of working. The respondents also viewed the shared vision as a necessity to ensure that the implementation is supported by the end-users:

“. . by running initial testing of this technology, we can set up a vision like: ‘this is how we want to work in the future’, because that’s what our workers and professionals said. It’s their voice that needs to be heard and form the goal or vision” (R10)

However, the incentive of integrating the technology in a strategy requires a clear understanding of how the opportunities of AR and BIM relate to an actual business value. Since construction companies measure the performance of their current processes inconsistently, creating incentives to any kind of innovation is challenging. AR manufacturers expressed that the lack of feedback regarding the performance of the construction processes made it difficult to showcase the positive effects of BIM through AR:

“Mistakes and construction errors are currently not being reported to the degree they should be. Therefore, when we say we can reduce the number of mistakes on a construction site, it doesn’t mean that much because there’s no statistics and people don't think the issue is that big” (R12)

Respondents advocated the formation of performance indicators to benchmark the performance of AR and BIM against current processes and use the technology in actual business cases. A ‘Key Account Manager’ who helps companies integrate AR in their processes expressed the following:

“*You shouldn’t have this because it's cool; you have to see the business value and run a proper ROI analysis and identify which Key Performance Indicators to use, to create a good foundation to take the next step. [. . .] without this groundwork you’ll have a hard time taking it past the pilot stage*” (R13)

By formulating KPI and conducting benchmarking, the positive effects of the technology can be better understood, which enable the formulation of an AR and BIM strategy that is focused on creating business value rather than merely technological evaluations.

Allocate staff. Most test do not go any further then pilots, and a common theme among respondents was that testing is limited to small teams that do not have enough allocated resources to develop the necessary processes. A ‘CEO’ of an AR hardware company, expressed the following concerns:

“AR testing is being conducted within the construction companies but the problem is that nobody has the time to push this further. The construction companies must hire one or two people whose sole task is to evaluate how AR can be used in the construction industry, identify all user cases, and then ensure that something comes from these projects” (R12)

As a part of the resources, it was expressed that the IT-department should have a greater role in this work, and drive these projects forward. But the digital approach in the construction industry has left many IT-departments too small and not functioning correctly to facilitate implementation of new technologies. A ‘Digital Development Coordinator’ described the current operations:

“Today we are just putting out fires, we need to catch up and structure ourselves so we can look forward and not just in the rear-view mirror” (R7)

Respondents highlighted the importance of putting demands on the IT-department so that it goes from being separated from the construction process, to being integrated with the rest of the organization. There is often no way of telling the difference between the IT-department at a construction company from any other industry and, therefore, it is not possible to utilize it to a desired extent when implementing new technologies:

> "*It has become its own entity that is relatively disconnected from the actual construction operations. They are mostly operating servers, computers, fixing Office suites and stuff like that, and are doing very little regarding actually changing the way we work*" (R10)

To address this, the IT departments must be integrated as a part of the business development function which may require recruitment of new competence.

Raise the status of BIM. A challenge to using AR and BIM relate to how the BIM models are currently treated in the construction process. A 'BIM Strategist' who is in charge of BIM implementation at a construction company described the current process:

> "*In parallel with this [BIM], there has been a process centered on drawings which we haven't moved past. The legal document is still the drawing and not the model"* (R4)

The result is that the models, rather than steering the project, are being updated to match the building and treated as a sideline. There is no way to actually integrate AR in the construction process if it is not possible to build according to the models:

> ". . .*people have never fully trusted the model and still want to be able to go back to the drawings because it feels safer. So the model has been something that has been on the side and has never really been built according to*" (R19)

To use BIM through AR at construction sites the models must have the same or preferably higher status than the drawings, otherwise the drawings will have to be constantly revisited. The current practices also entail additional work as both the drawings and the models have to be maintained separately. Thus, the old ways of working is still in control of the new, which makes it hard to distinguish the actual value that BIM provides:

> *"It's a general belief that BIM is expensive, the reason being that we never fully get rid of the old methods, so it's a false perception. We have to start on a blank slate and imagine how the process would look like with only BIM, and do that instead"* (R6)

If the value of BIM is not clear, it will be even harder to motivate the value of AR. The status of the model is a matter of reaching an agreement with the involved project partners, and is therefore fully manageable today.

Develop Model Maturity Index (MMI). If BIM models are to be used with AR, there must be a consensus regarding exactly what content should be displayed, how updates should be managed, and what information is needed in which phase. However, there is no obvious agreement among respondents regarding the correct approach. A 'Solution Specialist' at a BIM software developer advocated that it is a requirement to use digital-twins; the exact replicas of actual building elements:

". . .saying that is supposed to be 'roughly a door' or 'a type of window' is not enough. It's often visible at laser scanning and photogram measurement that the result does not line up according to the plans. If you cannot design more specifically, what's the point with AR?" (R6)

Meanwhile, an 'Architect/BIM Specialist' expressed concerns that the models would be too complicated or tedious to alter, and that modeling digital-twins right from the design does not fit well with the information that is available in the early stages of construction:

"The reason why we don't use precise objects from the beginning is that you do not know exactly which product you need, it can take up to 6 months with procurements, and there is a lot of aspects to consider" (R15)

A 'technical expert', who is part of developing BIM standards, confirmed that this is an area where more work is needed to stage industry standards. Thus, more standardized methods are needed, and it is necessary to work according to protocols, checklists, and have a united approach:

"Today, if you put two coordination models next to each other, you'll see that two completely different ways of working has been used; we can't have it like that" (R11)

Until then, the construction companies must develop and implement their own control documents that clarify which level of detail is required at a particular stage in the building process, to ensure standardized and consistent use of BIM:

"MMI shows the maturity requirements that the BIM model should have at different stages, i.e. is it enough that something in the design phase is displayed as a square, or does it have to be written in a construction document that it's made up of different parts?" (R7)

4.2.2 Technology

Improved positioning technology. The respondents confirmed the inadequate positioning of the holograms in AR hardware mentioned by Wang et al. (2014). However, the gravity of this problem proved to be greater than indicated in literature. Even though there are areas in which the positioning is 'good enough', the accuracy must be very high to get a widespread implementation. A 'BIM Developer' who evaluates AR for a construction company argued the following:

"The coordinate tracking is what needs to be fixed; it's the great obstacle we need to get over. If it's fixed, there is nothing that speaks against the technology, everything else can be managed and will be managed eventually" (R5)

There exist different methods for positioning models in the environment. The most prominent method is 3D mapping, where a 3D interpretation is made of the surrounding area and points are assigned to which the model can be positioned. A shortcoming is that there is no geographical reference, which is problematic if a model is to be placed outside where there are fewer reference points:

". . .you have no real reference where you are, it's bound to points instead of a geographical position. With GPS you can take a model, upload it, and then it's geographically in the right place" (R12)

At the time being, the best satellite navigation featured AR has accuracy between 5-10 centimeters. But this has the potential for significant improvement as projects such as EU's Galileo satellite navigation system and 5G mobile data become commercial, which will improve positioning both via network and satellite:

> *"GPS will most definitely have its place, but what's really interesting is when it's combined with 5G, then you get an error correction as one removes the error from the other"* (R14)

Currently, AR glasses that possess both Satellite Navigation and 3D mapping are scarce, but according to a 'Technology Specialist' at a major AR hardware manufacturer; there are ways to get around this until more integrated solutions are available:

> *"What you need to do is to use markers, that's how everyone solves it! It's like points to which the AR can position itself and makes it do certain things, like showing a hologram"* (R18)

Thus, there exists workarounds which increase the usability of BIM through AR, even though more permanent solutions are desirable.

Simplify the models. The amount of processing power in AR is limited as it is synonymous with weight and size, and there are several approaches among the manufacturers. Some opt for self-contained glasses or a separate computing box kept in the pocket, while others require a computer backpack. All approaches have limitations, but respondents agreed that the size is a big concern if the glasses were ever to be used by construction workers. A 'Digital Development Coordinator' said:

> *"Then you lose the whole thing! We can't expect the craftsmen to carry an extra tool bag just to get connection to their glasses, or it's going to be hard to motivate the practicality"* (R7)

The more portable AR glasses are often heavily restricted regarding the complexity of the models that can be shown (usually between 50-100 thousand polygons), but there are workarounds that still enable effective usage. One solution are software that compresses and simplifies the models, for instance by removing layers or details:

> *"We simplify geometries and hide the pieces that are not needed, so in order for AR-glasses to manage to display the models we filter out lots of data that is not relevant for the user to see"* (R14)

However, this necessitates requirement specifications to ensure that the usability of the models does not get compromised through the removal of details. Thus, the file compression must be done with regards to control documents, such as specialized MMI, referencing the required level of detail for AR in specific stages in the construction process.

Cloud computing. The reason for the modest computing power is that self-contained AR glasses use processors that are no better than cell phones. An area of development that could reduce these issues is cloud computing, which would virtually remove any conceivable limits regarding the models that can be shown. An 'owner' of a software developing company, specialized in AR for construction applications, tested this technology:

> *"There exists different technologies for displaying AR, and one such is streaming i.e. that you have a powerful computer remotely streaming the video content to AR, it's very promising"* (R14)

However, this presupposes stable internet connectivity at the entire construction site which is often nonexistent. Those sites where internet access is available cannot provide low enough latency (≈1ms) which is needed to avoid motion sickness from the AR glasses:

> *"We have no network connection at the [construction] site today, well we do in the barracks, but as soon as you leave it's nothing. This has to do with the fact that there is no technology in need of constant connection today"* (R7)

This is an area that will see significant changes with the upcoming introduction of 5G, as it can provide high connectivity with very low latency even in remote areas. Furthermore, the drawing distance of the models, which is about 100 meter, will rise significantly with increased computing power.

Active role in development. To drive these issues and get tailored solutions to their specific needs, the respondents argued that it is necessary to take an active role in the development of AR. Currently most AR options are aimed towards designers or manufacturing:

> *"Different industries have different technology requirements, so the construction industry must push for our specific needs in technology development"* (R7)

This met agreement from the AR developers who also noted that they have not prioritized creating construction specific solutions because the interest from the construction industry has not been conveyed. Some hardware developers, such as a 'Key Account Manager', did not know that the construction industry was testing, or even interested in AR:

> *"The pure realization that construction companies actually tests this, and has been willing to bring AR glasses to a construction site as an additional device is really interesting"* (R13)

Other manufacturers had evaluated the viability in the industry themselves and concluded that there was no interest, and were positively surprised when contacted by the authors:

> *"We investigated the opportunities to integrate our technology at the construction site ourselves, and they are large. However, interest has been quite weak from the industry"* (R20)

If the construction industry would truly show that they are an actor to count with when it comes to AR, it could turn into a catalyst for the development of industry adapted hardware:

> *"If you notice an interest and a pull-effect, instead that we as developers has to push the construction industry, it becomes very interesting, then it can really be a giant starting to wake up"* (R13)

4.2.3 User

Organic dispersion. It does not matter how promising a technology is if it does not have the support from the end users. A current implementation challenge is to make the users understand the true value the technology can bring to their respective area, as the 'Head of Logistics' emphasized:

> *"I really what to see the value before committing to a larger digitalization"* (R8)

An underlying issue is a disconnect between management and the workers. Technology is injected into organizations without further context or explanations of its benefits, which create a gap where the managerial vision is not communicated to the users:

> *"It has not been anchored well enough, and the workers have to read between the lines; you need to do the new things in addition to your usual job, then what gets the priority?"* (R13)

It was highlighted that a successful implementation require engagement from both managers as well as the users, which stands in agreement with the combination of Bottoms-up and Top-down engagement proposed by Vass & Gustavsson (2017). To create Bottoms-up engagement, users must grow accustomed to the technology and be provided with appropriate training. According to a 'BIM Strategist' it is necessary to engage the users by steering the conversation away from the technology to focus on the actual value:

> *"AR in construction can solve existing problems associated with looking at the model. But it will take time, it's not the technical solutions that will convince the workers, instead we have to precede with everything from pilot- and test projects and let the good example lead the way"* (R4)

To meet this challenge the respondents advocated an organic dispersion of the technology, where pilot studies are used to showcase benefits and generate interest. By doing this, a pull-effect can be achieved and the workforce becomes the driving force for implementation, which in turn reduce the resistance to change presented by Wang et al. (2014). The pull-effect also eases the workload for those conducting the implementation that, instead of convincing others of the technology's potential, can focus at the actual implementation:

> *"The construction workers thought it was really interesting, additionally, when we showed it; personnel from other areas [than reinforcement] discovered that they also would like to work with it, so the reputation spread and now we have six pilot projects"* (R10)

Develop for a specific area. An implementation of AR and BIM will, as discussed in Chapter 4.1, drastically increase the access to information. Further confirming the risk of information overload mentioned by Chu et al. (2018), there were concerns among the respondents related to the sheer volume of information BIM models subject the user to:

> *"There is a risk of getting too much information, unlike traditional documents where there is one thing at a time"* (R4)

The balance between displaying sufficient information to enhance processes, while at the same time avoiding cluttering of the worker's field of view, is important. Thus, interfaces must be developed that only display information that is relevant to the specific task at hand:

> *". . .the possibility to bring forth information must be done in a delicate way, so that it does not get out of hand. Since it's not about giving much, but the right information. It's not about getting an entire information model on a screen, but instead getting the right information to support a particular process"* (R4)

A 'CAD/BIM Specialist' who had conducted several tests with BIM through AR, explained that this is best initiated through choosing a very specific sub-operation and develop the system to work really well for that task; then the system can be expanded to involve other processes:

> *"We started from nothing and developed everything for a particular operation"* (R10)

It was noted that the resistance to change among the users, also mentioned by Wang et al. (2014), relates to the perceived ease of use of the technology. Thus, by focusing at high usability for specific sub-operations, the risk of resistance can be mitigated.

5. DISCUSSION AND FUTURE RESEARCH

By collecting accounts from practical testing of AR and BIM on construction sites this study can confirm that the technology can reduce the information gap between design and construction. This is achieved by enhancing the communication of the design intent through increased spatial cognition, increased information flow, and emancipated resources. Additionally, by not only increasing information to, but also from the construction site, AR can provide feedback of process performance and become a tool for increased efficiency and process development. This confirms that there is a lot to gain, and now companies know what to expect from an implementation.

Even though this study shows that significant work will be needed in a range of areas before BIM through AR can be widely used at construction sites, it also shows that the barriers are manageable and that there is much to gain by initiating early work with the technology. However, out of the three areas that need consideration in the implementation of BIM through AR (*Process*, *Technology*, and *User*), some are more manageable than others. *Process* is for example the dimension that construction companies have the greatest ability to effect on their own, as it relates to the current management of the organization and can be handled internally. This dimension lays the foundation for an implementation as it creates the necessary organizational setting, thus, we argue that this is where the initial focus should be. However, some process-related barriers will be more challenging than others to overcome, for instance the evolution of the IT department, which may require new sets of competences. To succeed, the construction industry will have to change its image from a low-tech industry, to a workplace desirable for IT talents. The *Technology* dimension poses a different challenge since these barriers are not primarily solved in-house, and rather depend on the cooperativeness of external actors and the pace of technological development. While initially focusing on the *Process* dimension, the *Technology* dimension should be attended in continuous dialogue between other industry actors and developers. Finally, the *User* dimension revolves around supporting the users and actual implementation of the technology, and inherently contains factors dependent on pilot testing. Therefore, it presupposes that there has been some work with the previous dimensions. Successful management of this dimension depends on extensive dialogue with users, but also partnerships with e.g. AR developers in order to take action on their feedback.

5.1 Managerial contribution

The frameworks in Table 4 and Table 5 hold contributions for managers seeking to implement BIM through AR. Managers are given information regarding both the benefits to be gained from BIM through AR, the inherent barriers to implementation, and what measures to take.

However, due to the wide range of dimensions in need of consideration, an implementation can be hard to grasp and the process can seem almost overwhelming. Therefore, we saw the need for a tool that visualizes the process of BIM through AR implementation. To that end, using our combined understanding of AR and BIM generated during this study, we created a roadmap that gives an overview of different levels of implementation, and allows companies to position themselves along the process, Figure 4. The roadmap provides managers with a sense of direction regarding the steps that needs to be taken to achieve full implementation of BIM through AR in construction. Each level describes a set of organizational features characterizing an organization residing on the respective level. The axes describe the AR usage of each level and also give information regarding the degree of technological maturity that is required. Through the red lines, the roadmap visualizes an approximation of how far most construction companies could reach as of today. In doing so, it acts as a tool for assessing what level the organization resides in at the moment, and the requirements needed to reach the next. Observe that the levels in practice do not have to be "black and white", and some companies will certainly end up in between. The roadmap also illustrates the relationship between technology and organizational development and that full implementation of AR and BIM will require both technological as well as organizational innovation. The roadmap can also be found in *Appendix 6 – Roadmap*. In combination with the frameworks that give more concrete information regarding how these areas can be handled, managers can use the roadmap to lay the foundation towards an AR and BIM strategy.

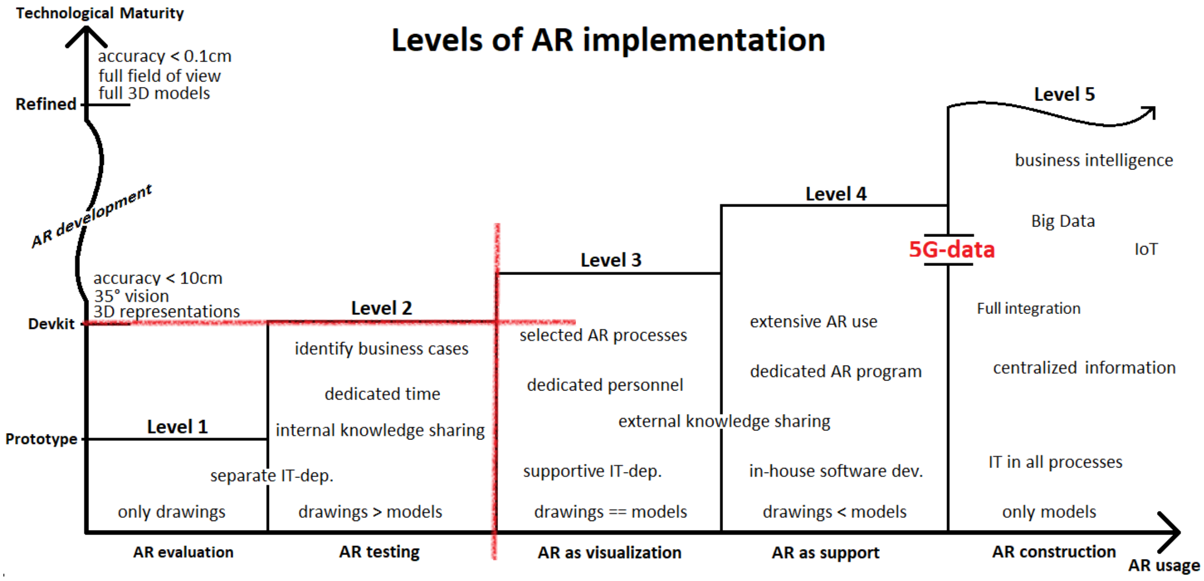

Figure 4: Roadmap for implementation that allows managers to evaluate their organization

5.2 Theoretical contribution

By fulfilling the research purpose this study has extended the scope of AR and BIM research by collecting the experiences of testing in real life construction environments, thus, also filling the research gap identified by Jiao et al. (2013), Chu et al. (2018) and Chalhoub & Ayer (2018). Furthermore, this study confirms and expands contemporary literature by bringing AR and BIM research past the initial clinical testing, to instead focus on facilitating the implementation of the technology within the construction industry, by identifying concrete measures to overcome barriers. This has been done by compiling the barriers previously identified in literature into the dimensions; *Technology* and *User*, as well as identifying a new dimension called *Process*, which include the soft organizational aspects affecting AR and BIM implementation. Among these are the current usage of BIM within the industry, which is fragmented and often used in parallel with traditional drawings, and the approach to AR pilot testing which has been restricted to merely technical evaluations and require greater coordination.

Expanding on the theories of the Media Richness of BIM by Svalestuen et al. (2017) it was found that a combination of AR and BIM constitutes a medium that is perceived richer than BIM on its own, and that it can enhance the current communication between design and construction practitioners. The findings in this study also support the notion of Vass and Gustavsson (2017) that a combination of both a push- and grow approach is required for BIM implementation. Additionally, this can be extended to the combination of AR and BIM since managerial support as well as an organic dispersion of the technology were significant success factors for implementation.

5.3 Limitations and future research

Challenges with AR such as the need for a wider field of view, stronger holograms, longer battery life, and lighter products have been identified, but not thoroughly addressed in the findings. While all testers agreed these details were lackluster; they are not areas in which the construction industry should direct their effort. Hardware developers confirmed that these will be improved with or without the involvement of the construction industry. These are nevertheless in need of improvement as they inherently limit the use of AR, thus, they are partly included in the roadmap.

The construction companies interviewed in this study are active in Sweden and have over 2,000 employees, thus, the results reflect their degree of digitalization and usage of AR and BIM. Future studies should investigate how newly formed and smaller construction companies establish their business around the available digital technology. More specific studies are also required regarding the identified dimensions and barriers. For instance the possibilities of 5G in the context of the construction industry, and how higher positioning accuracy and latency-free data streaming will affect the field. Furthermore, while this study focused on AR using HMD, future studies should investigate whether the use of other more readily available AR platforms, such as HHD, can be used as an initial step to let construction companies grow accustomed to AR. Finally, researchers are encouraged to update the roadmap as more information and knowledge appear. When specific studies have been conducted, the factors can certainly be positioned with higher accuracy.

6. CONCLUSION

Although this research showed that there are several areas in need of consideration; it has also shown that there exists solutions. At the time of writing, AR is not ready for widespread implementation and there will be considerable time before it becomes available for the average construction worker. However, AR is capable of much and there exist out-of-the-box solutions that can import and display 3D models, which enable the technology to be tested right away. This was illustrated by several respondents who despite some technological shortcomings, found great usage of the technology for different construction processes. Our belief is that AR has great applications, and developers are positive the technological progress will proceed. The hardware available today is 'generation one', and it is easy to draw parallels to the lackluster performance inherent with first generation technologies in other areas, which has since developed greatly. When the technology is ready, the support structures in the organizations must be too. Construction companies now have the chance to be in phase, or even lead the technological development. Use this report to explain the possibilities, understand the shortcomings, and develop the solutions.

REFERENCES

Abdul Rahman, I., Memon, A. H., Azis, A., Asmi, A., & Abdullah, N. H. (2013). Modeling causes of cost overrun in large construction projects with partial least square-SEM approach: contractor's perspective. Research Journal of Applied Sciences, Engineering and Technology, 5(6), 1963-1972.

Ajam, M., Alshawi, M., & Mezher, T. (2010). Augmented process model for e-tendering: towards integrating object models with document management systems. Automation in Construction, 19(6), 762-778.

Azhar, S., Khalfan, M., & Maqsood, T. (2015). Building information modelling (BIM): now and beyond. Construction Economics and Building, 12(4), 15-28.

Azhar, S., Nadeem, A., Mok, J. Y., & Leung, B. H. (2008, August). Building Information Modeling (BIM): A new paradigm for visual interactive modeling and simulation for construction projects. In Proc., First International Conference on Construction in Developing Countries (pp. 435-446).

Azuma, R. T. (1997). A survey of augmented reality. Presence: Teleoperators and virtual environments, 6(4), 355-385.

Bernstein, M., Jones, S. (2012) SmartMarket Report: The Business Value of BIM in North America. McGraw Hill Construction.

Bernstein, M., Jones, S., A., & Young, N., W. (2008). SmartMarket Report: Building Information Modeling (BIM). McGraw Hill Construction.

BIM Alliance (2017) ”BIM Alliance om BIM”. http://www.bimalliance.se/vad-aer-bim/bim-alliance-om-bim/ Retrieved: 2018-01-16

Braun, Virginia; Victoria Clarke (2006). "Using thematic analysis in psychology". Qualitative Research in Psychology. 3 (2): 83. doi:10.1191/1478088706qp063oa

Bresnen, M., & Marshall, N. (2000), “Partnering in construction: a critical review of issues, problems and dilemmas”, Construction Management and Economics, Vol. 18 No. 2, pp. 229-37.

Bryde, D., Broquetas, M., & Volm, J. M. (2013). The project benefits of building information modelling (BIM). International journal of project management, 31(7), 971-980.

Chalhoub, J., & Ayer, S. K. (2018). Using Mixed Reality for electrical construction design communication. Automation in Construction, 86, 1-10.

Chen, K., Lu, W., Peng, Y., Rowlinson, S., & Huang, G. Q. (2015). Bridging BIM and building: From a literature review to an integrated conceptual framework. International journal of project management, 33(6), 1405-1416.

Chi, H. L., Kang, S. C., & Wang, X. (2013). Research trends and opportunities of augmented reality applications in architecture, engineering, and construction. Automation in construction, 33, 116-122.

Chu, M., Matthews, J., & Love, P. E. (2018). Integrating mobile Building Information Modelling and Augmented Reality systems: An experimental study. Automation in Construction, 85, 305-316.

Daft, R. L., & Lengel, R. H. (1983). Information richness. A new approach to managerial behavior and organization design (No. TR-ONR-DG-02). Texas A and M Univ College Station Coll of Business Administration.

Dainty, A., Moore, D. and Murray, M. (2006), Communication in Construction, Taylor & Francis, New York, NY.

Dennis, A. R., & Kinney, S. T. (1998). Testing media richness theory in the new media: The effects of cues, feedback, and task equivocality. Information systems research, 9(3), 256-274.

Dubois, A., & Gadde, L. E. (2002). Systematic combining: an abductive approach to case research. Journal of business research, 55(7), 553-560.

Eastman, C. M., Eastman, C., Teicholz, P., & Sacks, R. (2011). BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors. John Wiley & Sons.

Egan, J. (1998), Rethinking Construction: Report of the Construction Task Force, HMSO, London.

Eisenhardt, K. (1989), "Building theories from case study research", The Academy of Management Review, Vol. 14 No. 4, pp. 532-50.

Fitzgerald, M., Kruschwitz, N., Bonnet, D., & Welch, M. (2014). Embracing digital technology: A new strategic imperative. MIT sloan management review, 55(2), 1.

Flyvbjerg, B., Holm, M. K. S., & Buhl, S. L. (2003). "How common and how large are cost overruns in transport infrastructure projects?". Transport Reviews, 23(1), 71-88

Frame, J. D. (1997). Establishing project risk assessment teams. In K. Kahkonen & K. A. Artto (Eds.), Managing risks in projects: E & FN Spon, London.

Grilo, A., & Jardim-Goncalves, R. (2010). Value proposition on interoperability of BIM and collaborative working environments. Automation in Construction, 19(5), 522-530.

Grossman, R., & Richards, T. (2017). The Industries that are being affected the most by Digital. Harvard Business Review. Boston, MA: Harvard Business School Publishing.

Gu, N., & London, K. (2010). Understanding and facilitating BIM adoption in the AEC industry. Automation in construction, 19(8), 988-999.

Harty, C. (2008). Implementing innovation in construction: contexts, relative boundedness and actor-network theory. Construction Management and Economics, 26(10), 1029-1041.

Hergunsel, M. F. (2011). Benefits of building information modeling for construction managers and BIM based scheduling.

Hou, L., Wang, X., Bernold, L., & Love, P. E. (2013). Using animated augmented reality to cognitively guide assembly. Journal of Computing in Civil Engineering, 27(5), 439-451.

Jiao, Y., Zhang, S., Li, Y., Wang, Y., & Yang, B. (2013). Towards cloud augmented reality for construction application by BIM and SNS integration. Automation in construction, 33, 37-47.

Kadefors, A. (2004), "Trust in project relationships – inside the black box", International Journal of Project Management, Vol. 22 No. 3, pp. 175-82.

Karrbom Gustavsson, T., & Gohary, H. (2012). Boundary action in construction projects: new collaborative project practices. International Journal Of Managing Projects In Business, (3), 364. doi:10.1108/17538371211235272

Li, X., Yi, W., Chi,. H, Wang, X., Chan, A. P. C. (2018). A critical review of virtual and augmented reality (VR/AR) applications in construction safety. Automation In Construction, Vol 86, 150-162.

Lincoln, Y. S., & Guba, E. G. (1985). Naturalistic inquiry (Vol. 75). Sage.

Manyika, J., Ramaswamy, S., Khanna, S., Sarrazin, H., Pinkus, G., Sethupathy, G., & Yaffe, A. Digital America: A tale of the haves and have-mores. McKinsey Global Institute (2015)

Matthews, J., Love, P. E., Mewburn, J., Stobaus, C., & Ramanayaka, C. (2018). Building information modelling in construction: insights from collaboration and change management perspectives. Production Planning & Control, 29(3), 202-216.

Mekni, M., & Lemieux, A. (2014, April). Augmented reality: Applications, challenges and future trends. In Applied Computational Science—Proceedings of the 13th International Conference on Applied Computer and Applied Computational Science (ACACOS '14) Kuala Lumpur, Malaysia (pp. 23-25).

Milgram, P., & Kishino, F. (1994). A taxonomy of mixed reality visual displays. IEICE TRANSACTIONS on Information and Systems, 77(12), 1321-1329.

Neff, G., Fiore-Silfvast, B., & Dossick, C. S. (2010). A case study of the failure of digital communication to cross knowledge boundaries in virtual construction. Information, Communication & Society, 13(4), 556-573.

Nguyen, L. D., Tran, D. Q., Nguyen, A. T., & Le-Hoai, L. (2016, October). Computational model for measuring project complexity in construction. In Fuzzy Information Processing Society (NAFIPS), 2016 Annual Conference of the North American (pp. 1-5). IEEE.

Oxford Economics. (2015). The UK's £92 BN Digital Opportunity. Retrieved from http://www.oxfordeconomics.com/my-oxford/projects/324416

Peng, G. (2011). Inter-organizational information exchange, supply chain compliance and performance. Wageningen Academic Pub.

Porter, M., E. & Heppelmann, J., E., (2017). Why every organization needs an augmented reality strategy. Harvard Business Review. Boston, MA: Harvard Business School Publishing

Saunders, M., Lewis, P., & Thornhill, A. (2016). Research Methods for Business Students. Harlow: Pearson.

Shen, W., Shen, Q., & Sun, Q. (2012). Building Information Modeling-based user activity simulation and evaluation method for improving designer–user communications. Automation in Construction, 21, 148-160

Sugarman, B. (2001). Push and grow theories in change management: gateways to understanding organizational learning

Suk, S. J., Ford, G., Kang, Y., & Ahn, Y. H. (2017). A Study on the Effect of the Use of Augmented Reality on Students' Quantity Take-off Performance. In ISARC. Proceedings of the International Symposium on Automation and Robotics in Construction (Vol. 34). Vilnius Gediminas Technical University, Department of Construction Economics & Property.

Svalestuen, F., Knotten, V., Lædre, O., Drevland, F., & Lohne, J. (2017). Using building information model (BIM) devices to improve information flow and collaboration on construction sites. Journal of Information Technology in Construction (ITcon), 22(11), 204-219.

Toyama, M. (2006). A Transaction Cost Approach to the Effects of Network Growth on Cost and Price. Contemporary Management Research, 3(1), 71.

Vass, S., and T. V. Gustavsson. 2017. “Challenges when Implementing BIM for Industry Change.” Construction Management and Economics: 1–14. doi:10. 1080/01446193.2017.1314519

Volk, R., Stengel, J., & Schultmann, F. (2014). Building Information Modeling (BIM) for existing buildings—Literature review and future needs. Automation in construction, 38, 109-127.

Wang, X., & Dunston, P. S. (2006). Compatibility issues in Augmented Reality systems for AEC: An experimental prototype study. Automation in construction, 15(3), 314-326.

Wang, X., Love, P. E., Kim, M. J., Park, C. S., Sing, C. P., & Hou, L. (2013). A conceptual framework for integrating building information modeling with augmented reality. Automation in Construction, 34, 37-44.

Wang, X., Ong, S. K., & Nee, A. Y. C. (2016). A comprehensive survey of augmented reality assembly research. Advances in Manufacturing, 4(1), 1-22.

Wang, X., Truijens, M., Hou, L., Wang, Y., & Zhou, Y. (2014). Integrating Augmented Reality with Building Information Modeling: Onsite construction process controlling for liquefied natural gas industry. Automation in Construction, 40, 96-105.

Wang, J., Wang, X., Shou, W., & Xu, B. (2014). Integrating BIM and augmented reality for interactive architectural visualisation. Construction Innovation, 14(4), 453-476.

Weinberger, M. (2017) 2 April. The smartphone is eventually going to die, and then things are going to get really crazy. Business Insider. Accessed: 2018-02-01 From: http://nordic.businessinsider.com/death-of-the-smartphone-and-what-comes-after-2017-3?r=US&IR=T

Wikforss, Ö. and Löfgren, A. (2007), “Rethinking communication in construction”, ITcon, Vol. 12, pp. 337-45.

Wood, G., McDermott, P. and Swan, W. (2002), “The ethical benefits of trust-based partnering: the example of the construction industry”, Business Ethics: A European Review, Vol. 11 No. 1, pp. 4-13.

Wu, H. K., Lee, S. W. Y., Chang, H. Y., & Liang, J. C. (2013). Current status, opportunities and challenges of augmented reality in education. Computers & education, 62, 41-49.

Yeh, K. C., Tsai, M. H., & Kang, S. C. (2012). On-site building information retrieval by using projection-based augmented reality. Journal of Computing in Civil Engineering, 26(3), 342-355.

Zhou, F., Duh, H. B. L., & Billinghurst, M. (2008). Trends in augmented reality tracking, interaction and display: A review of ten years of ISMAR. In Proceedings of the 7th IEEE/ACM International Symposium on Mixed and Augmented Reality (pp. 193-202). IEEE Computer Society.

Zou, P. X., Zhang, G., & Wang, J. (2007). Understanding the key risks in construction projects in China. International Journal of Project Management, 25(6), 601-614.

APPENDIX

Appendix 1 - Empirical Process

The data collection was divided into four blocks; each designed to provide knowledge for the next. In the **first block** of interviews, the questions were based on the findings in the literature. The first interviews were conducted to receive broad knowledge regarding the subjects of BIM and AR and the interviewees were mainly BIM coordinators at large construction firms. These interviews laid the foundation for understanding the current use and situation of BIM in order to formulate questions for the interviewees with actual experience of testing with BIM through AR at constructions sites. The **second block** of interviews was conducted to gather knowledge regarding previous testing of AR and BIM at construction companies. The purpose was to collect the contemporary industry experiences and to identify both success factors and problems with BIM and AR usage on construction sites. These interviews were built upon a majority of open and reflective questions to collect as many nuances and details as possible. The **third block** focused on the issues exposed in previous test projects and contained more technical and specific questions regarding the technology. These interviews were directed towards AR and BIM hardware and software developers and aimed to complement the data with the developers' point of view regarding the issues and possible solutions. The **fourth block** was a workshop held at a construction company. This stage worked as a confirmation for the information gathered from the previous blocks to provide additional validation towards the result.

Appendix 2 – Interview guides

Interview guide: BIM-users

Warm-up questions:

- What is your background and main responsibilities?
- How long have you been working for the company?
- How long have you worked with BIM?

Initial BIM questions:

- How would you describe BIM in a couple of minutes?
  - Software or process?

- How established is BIM in the construction industry? Is it widely used?

- How is BIM used in construction projects today?
  - Is BIM especially prevalent in certain types of construction projects?
  - Where in the construction process does the BIM usage start, where does it end?

- How has BIM affected the construction process?
      - Communication
      - Cooperation

- How has the transition to BIM worked?
  - Is the reaction to BIM positive or negative?

- What are the greatest challenges regarding BIM?
  - Technology (Compatibility)
  - Process (the status of the models)
  - Usability (training, resistance to change)

- Which are the strongest aspects with BIM?

Reflective BIM & AR questions:

- Do you see any potential applications of BIM that are currently not used?
  - How can BIM be used to improve the current construction process?

- Have you experienced/heard of BIM being used on the construction site?
  - Which medium was used to display the models? (AR, tablets, BIM-stations)
  - How was it used?
  - What value did it bring?

- Have you heard of the possibility to use AR to display BIM models?
    - When / how did you hear about it?
    - How do you define Augmented Reality (vs. Mixed Reality)?
    - What possible applications do you see with such a technology?
    - What challenges do you see with this technology?

Closing thoughts:

- Is there anything you want to add?
- Is there anyone you think we should contact that could be of interest for this project?
- Why did you agree to make this interview?
- Do you want to receive the transcription of the interview?
- Can we book an additional interview with you? (IF DEEMED NECESSARY)

Interview guide: AR and BIM testers:

Warm-up questions:

- What is your background and main responsibilities?
- How long have you been working for the company?
- How long have you worked with BIM and/or AR?
- Do you distinguish between Augmented Reality and Mixed Reality? (definitions?)

The project:

- What BIM and AR projects have you been involved in?
    - Can you describe the execution of the tests?
        - What was tested?
        - Where did the tests take place?
        - Which stage in the construction process?

- Why was the project executed?
        - Effectivization
        - Branding
    - What are the implications for this technology on the construction industry?
    - What value does BIM models have at the construction site?

- Why did you use AR-Headsets (or other method) to display BIM?
    - Why did you choose this particular technology?
        - Did you look at other methods (tablets, smartphones, BIM-stations)
        - How did they perform against each other? (Selection process)
        - Do they face the same challenges?

- Where the included solutions in the AR system sufficient?
    - Were you required to develop your own software solutions?
        - In-house or external developer

Learning's from the project:

- What was the key learning's from the projects?
- Did you encounter any challenges (both in AR & BIM)?
    - Technology related:
        - Insufficient hardware (tracking, position, field of view, memory, resolution)
        - Compatibility issues / lack of standardization
        - Lack of previous research and testing
    - User related:
        - User training / usability
        - Resistance to change

        - Information overload
    - Process related:
        - In the organization & the construction industry?
        - What specific problems does the construction industry have to solve?

- Did you identify any success factors regarding implementation (both in AR & BIM)?
    - Technology related
        - What needs to be done to overcome the technical issues?
    - User related
        - Improved understanding
        - Access to information
        - Reduction in errors
    - Process related
        - Grass-root engagement
        - Strong engagement from top management

- Is full scale industry implementation of the technology realistic?
    - In which settings?
    - What are the challenges?

- Is any particular knowledge missing in the area of AR & BIM?
- Has your perception regarding BIM & AR changed during the scope of the project?
- To which degree is this technology used today?
    - In your organization?

Closing thoughts:

- Is there anything you want to add?
- Is there anyone you think we should contact?
- Why did you agree to make this interview?
- Do you want to receive the transcription of the interview?
- Can we book an additional interview with you? (IF DEEMED NECESSARY)

Interview guide: AR Hardware developers

Warm-up questions:

- What is your background and main responsibilities?
- How long have you been working for the company?
- Do you distinguish between Augmented Reality and Mixed Reality? (Definitions?)

The products:

- Can you describe your company's AR Hardware?
  - How are the holograms displayed?
  - Does it interact with the surrounding environment?
  - What differentiates your product from competitors?
    - What are your strengths & weaknesses / unique features?

- Which customers are you mainly targeting? Why?
  - How do they use AR, in which settings?
  - How are your customers affecting the product development?

AR in the construction industry:

- What do you know about the usage/tests with AR in the construction industry?
  - Have you been part of any testing?

- What prospects do you see regarding integrating AR in the construction industry?
  - Has the industry showed interest?
  - Which is the best setting for using AR in construction?
  - Where does the displayed information come from? BIM?
    - What demand does this put on the BIM models?

- What are according to you the challenges to use AR in the construction industry?
    - Lack of interest
    - Resistance to new technology
    - Lack of competence
  - Do you have/had any contact with construction companies regarding AR?

The identified challenges:

___________ Position ____________

- How does the hardware navigate its environment, why?
  - GPS tracking, Coordinate grid, QR-codes, 3G/4G, Other?
  - How precise is the model placement? In which settings?
  - **Positioning accuracy** of the models is a major challenge according to the construction industry, how can this be improved?

- **GPS-navigation** is a feature that is somewhat lacking in AR hardware today:
  - Is it needed?
  - Is it available in your product, what is the accuracy?
  - Are there any major breakthroughs in GPS-precision ahead? EUs Galileo-project?

- Most constructions sites lack stable **connectivity** in the form of WiFi or sometimes proper 3G/4G signals; especially inside buildings under construction
  - 5G?
  - Is this a problem? Is AR dependent on this type of connectivity?

___________ Hardware ____________

- How **large field of view** does your product have?

- AR HMD has a price that to some degree is too high for widespread implementation, what are your views on the current **costs** of AR hardware?
  - According to some this makes HHD (phones & tablets) more desirable as they have AR capabilities and are cheaper and more available, why should a company pay more for HMDs?

- Most AR is developed with an indoor use in mind, how is your hardware affected by an outdoor setting?

- Are there any limitation regarding size and complexity of the models that can be shown?

___________ Software _______________

- BIM models contain large amount of information and **Information overload** is a potential risk, how can AR distribute this information without exposing the workers to "too much"?

- There is a desire that AR systems should be "device independent" and that there should be **Interoperability** with other AR devices, is this possible?

- Which operating system do you use?
  - Is it for sale?
  - Which operating system is most widely used?

- There is a **lack of construction task specific software**, how are you working with your customers to develop specialized software?

    - What support is needed from the industry?

___________ Miscellaneous ____________

- **Increased collaboration with hardware developers** is considered a must for successfully implementing AR in construction, what are your thoughts on this?
    - Have your company been approached by construction companies?
    - How is it possible to shape the hardware for specific needs?

- What would you need from the construction companies in order to begin to their perceived challenges with the technology?
    - Are any of them unique for the industry?

Closing thoughts:

- Is there anything you want to add?
- Is there anyone you think we should contact?
- Why did you agree to make this interview?
- Do you want to receive the transcription of the interview?
- Can we book an additional interview with you? (IF DEEMED NECESSARY)

Interview guide: AR Software developer

Warm-up questions:

- What is your background and main responsibilities?
- How long have you been working for the company?
- How long have you worked with AR?

The software:

- Describe the software you are providing:
    - Which problems does it solve?
    - What differentiate your solution from others on the market?
    - Who is your typical customer and what do they request?

- Which type of operating system is most commonly used in AR?
    - Which one is best from a developer's point of view?
    - Which one is best from a usability standpoint?

The hardware:

- Do you distinguish between Augmented Reality and Mixed Reality?
    - Why / How?

- Which brands of AR hardware do you work with?
    - Why specifically these brands?
    - What are the strengths of the respective brands?
    - Head Mounted Displays vs. Handheld Displays (pros and cons)?

The projects:

- Which types of AR projects have you been a part of in the construction industry?
    - Which companies?
    - How is the interest of AR in the construction industry?
    - Can you describe the project?

- What were the main challenges in the project?
    - Hardware limitations?
        - Model placement
        - GPS-positioning
        - Processing power
        - Cost of hardware
        - Field of view
        - Weight and size
        - Ruggedness

    - Software limitations?
        - How do you avoid information overload?
        - Context awareness
        - User training
        - Interoperability (Can the software be used by another AR brand?)
    - Did the construction industry have reasonable expectations?
        - Could they specify their problems and demands?
        - Did you lack any information from the construction companies?
        - Was there anything you wanted, but could not do?

- Did you notice any success factors in the project?
    - From your company's side?
    - From the customers side?

Reflection:

- What potential do you see for AR in the construction industry?
    - Is the technology mature?
    - Is the construction industry mature? If not, what can be done to change this?

- What are according to you, the greatest challenges to use AR in the construction industry?
    - What does the construction industry need to do to facilitate your work as a software developer?

Closing thoughts:

- Is there anything you want to add?
- Is there anyone you think we should contact?
- Why did you agree to make this interview?
- Do you want to receive the transcription of the interview?
- Can we book an additional interview with you? (IF DEEMED NECESSARY)

Appendix 3 – Original Quotes

Quote 1 - R1

Original - *"När man ska förklara hur något ska se ut så kan det inte bli bättre än att visa det med AR"*

Translated - *"When explaining how something should look like, it doesn't get better than doing it with AR"*

Quote 2 - R6

Original - *"Tänk dig när du kommer till ett bygge och det första du måste göra är att läsa in dig på ritningarna för att få en förståelse, lycka till med att få en tydlig bild och förståelse för projektet, målet, samt vad som förväntas av dig med hjälp av det! Alla sitter med olika uppfattningar"*

Translated - *"Imagine coming to the site and the first thing you need to do is to read up on the drawings, good luck getting a clear understanding of the project, goals, and what is expected of you only with the help of that! Everyone make their own interpretations"*

Quote 3 - R1

Original - *"Bakgrunden till varför vi gör detta är att byggbranschen har många aktörer där det är många personer som alla skall ge information till varandra"*

Translated - *"The background to why we are doing this is that the construction industry consists of many actors with many people who all must send information to each other"*

Quote 4 - R10

Original - *". . .så fort du ska hämta de färdiga ritningarna från ritningsbordet så har de blivit inaktuella för att det kommit en ny version, det är den krassa verkligheten."*

Translated - *". . .as soon as you collect the drawings from the drawing table they are outdated as a new version has already been released, that's the reality"*

Quote 5 - R4

Original - *"När man har information som flödar genom hela processen med samma modell; då effektiviserar man på ett annat plan än att bara leta efter befintliga fel"*

Translated - *"When you have information flowing throughout the process from the same model; then you effectivize on a whole other level than simply looking for existing errors"*

Quote 6 - R14

Original - ". . .detta ger intelligence om allt från hur vi kan göra med logistikplaneringen för leverans av betong till att även se vilka iläggningsmetoder som är mest effektiva för olika typer av element"

Translated - *". . .this gives us intelligence about everything from planning the logistics of delivering concrete to seeing what methods of inserting rebars is the most efficient for different types of elements"*

Quote 7 - R7

Original - *"Det ju också mycket rent arbete vi lägger ner för att administrera papper vid förändringar och revideringar i ritningar för då skall allting flyttas och sorteras manuellt, det skapar inte värde för kunden"*

Translated - *"We also put in a lot of work administrating paper due to changes and revisions of drawings because everything has to be moved and sorted manually, this doesn't create value for the customer"*

______________________________**Quote 8 - R2**______________________________________

Original - *"Vi har alltid velat gå åt det här hållet, för då blir det i samordningsprocessen mycket lättare när man har allt i 3D. Vi har börjat göra det innan också, men har då fått fördumma alla 3D modeller och göra snitt i 2D och det har varit som ett extra steg, och det tog vi bort då igenom det här"*

Translated - *"We always wanted to move in this direction because the coordination process gets much easier when everything is in 3D. We had done it to some extent before, but we had to stupidize the 3D models by making 2D cuts, which implied additional work that we now are getting rid of"*

______________________________**Quote 9 - R12**_____________________________________

Original - *". . .det är vattentäta skott inom företagen och folk kommunicerar inte; det är personer som köper in AR, men sen är det en helt annan person från samma företag som också köper in som inte känner till att den andra finns"*

Translated - *". . .the companies are very compartmentalized, and people don't communicate; there are employees who buy AR hardware and then there's someone else doing the same thing within the same organization, but they don't know about each other"*

______________________________**Quote 10 - R7**_____________________________________

Original - *"många har tappat tillit till den strategiska utvecklingen och istället kört sitt eget race, men man stöter på återvändsgränder i den typen av utveckling då man märker att det krävs för mycket för att ta det till nästa nivå då det inte finns tid avsatt för detta"*

Translated - *"Many has lost their trust to the strategic development and instead run their own race, but they run into dead-ends in the development when they realize how much is required to take it to the next level as there's no dedicated time for this"*

______________________________**Quote 11 - R5**_____________________________________

Original - *"Det är ju vanligt att man sitter och arbetar med liknande saker i olika länder och att man har samma problem och då är det bra att man kan ha ett bollplank där vi kan dela erfarenheter. Därför skapade vi ett nätverk som går över landsgränserna för att komma framåt snabbare"*

Translated - *"It's not uncommon that we sit and work with similar things in different countries and that we share the same challenges. In those cases, it's good to have a sounding board were we can share experiences with each other, which is why we created an international network so that we can advance faster"*

______________________________**Quote 12 - R10**____________________________________

Original - *". . .vi måste börja se på varandra mer som allierade när det kommer till digitaliseringen snarare än konkurrenter, vi konkurrerar ju i kärnverksamheten inte i digitaliseringen. Vi måste lära oss att tänka på det sättet och inte se det som ytterligare ett konkurrensområde"*

Translated - *". . .we need to start seeing each other more as allies than competitors when it comes to digitalization, we compete in the core business not in digitalization. We need to learn to think in this manner and not see this as just another area of competition"*

____________________________Quote 13 - R14_________________________________

Original - *"Vi borde titta på något mer branschgemensamt initiativ där vi går genom IQ samhällsbyggnad [branschorganisation] eller annat för att i byggbranschen tillsammans kunna ställa krav på vad man vill ha. Då tror jag att man skulle få ett helt annat forum att kontakta hårdvaruleverantörer med"*

Translated - *"We should look into an industry wide initiative where we, through 'IQ Samhällsbyggnad' [trade organization] or some other actor, together outline requirements for what we need. This would give us a completely new forum with which we can reach out to hardware developers"*

____________________________Quote 14 - R6__________________________________

Original - *"många byggföretag går det inte jättebra för och det har inte med bostadsmarknaden att göra; Carillion gick exempelvis i konken för ett tag sen, 35 000 anställda, men de föll ändå. Då växer det istället fram nya företag som ser nyttan med den nya tekniken"*

Translated - *"it doesn't look to well for a lot of construction companies, and this has nothing to do with the housing market. Take Carillion that recently went bankrupt as an example; 35,000 employees and they fell all the same. In its' place, new companies that see the value of the new technology will emerge"*

____________________________Quote 15 - R14_________________________________

Original - *" . . .piloten ett instrument för att komma framåt, tekniken är ny men även arbetssätten och juridiken kommer behöver ses över"*

Translated - *". . .the pilot is an instrument to move forward, the technology is new but the ways of working and legal aspects will also need to be revised"*

____________________________Quote 16 - R14_________________________________

Original - *"Det är genom att trycka några projekt långt fram nu som vi hjälper både beställare och utförare att förstå vad de måste kravställa till nästa"*

Translated - *"It's by already pushing some projects really far that we can help both the client and provider to understand what requirements they need to set up to the next"*

____________________________Quote 17 - R10_________________________________

Original - *". . .genom att testa den här tekniken ganska basalt så kan vi sätta upp en vision om att 'så vill vi jobba i framtiden', för det har våra yrkesarbetare och yrkesledare sagt. Det är deras röst som ska göras hörd och bli målet eller visionen"*

Translated - *". . .by running initial testing of this technology, we can set up a vision like: 'this is how we want to work in the future', because that's what our workers and professionals said. It's their voice that needs to be heard and form the goal or vision"*

Quote 18 - R12

Original - *"i dagsläget så rapporteras inte misstag och felbyggnationer i den graden de borde. Så när vi säger att kan minska antalet misstag på en byggarbetsplats så betyder det inte så mycket, för att siffrorna finns inte och man tror inte att det är ett så stort problem"*
Translated - *"Mistakes and construction errors are currently not being reported to the degree they should be. Therefore, when we say we can reduce the number of mistakes on a construction site, it doesn't mean that much because there's no statistics and people don't think the issue is that big"*

Quote 19 - R13

Original - *"Man ska inte ha detta för att det är coolt, man måste se affärsvärdet och göra en bra ROI-kalkyl och att identifiera vilka Key Performance Indicators man vill ha så att man får ett bra underlag för att ta nästa steg, man måste se: 'Kan vi tjäna- eller spara pengar på det här?' Om svaret är ja, då är det inget problem att rulla ut, men utan det grundjobbet är det svårt, då blir man ofta hängande efter pilotstadiet"*
Translated - "*You shouldn't have this because it's cool, you have to see the business value and run a proper ROI analysis and identify which Key Performance Indicator to use to create a good foundation to take the next step. You have to investigate; 'Is this something we can make or save money on?' If the answer is yes, then there will be no problem implementing it, but without this groundwork you'll have a hard time taking this past the pilot stage*"

Quote 20 - R12

Original - *"Det genomförs tester med AR inom byggföretagen men problemet är att ingen har tid att driva detta vidare. Byggföretagen måste anställa en eller två personer vars enda uppgift är att utvärdera på hur man kan använda AR i byggindustrin, identifiera alla användarcase för tekniken och sen driva på så att det faktiskt blir någonting av de här projekten"*
Translated - *"AR testing is being conducted within the construction companies but the problem is that nobody has the time to push this further. The construction companies must hire one or two people whose sole task is to evaluate how AR can be used in the construction industry, identify all user cases, and then ensure that something comes from these projects"*

Quote 21 - R7

Original - *"Det är lite brandsläckning idag och där gäller det att komma ikapp och strukturera upp så man kan titta framåt och inte bara i backspegeln"*
Translated - *"Today we are just putting out fires, we need to catch up and structure ourselves so we can look forward and not just in the rear-view mirror"*

Quote 22 - R10

Original - *"det har blivit en egen verksamhet som är ganska frånkopplad från själva byggverksamheten, de håller mest på med att drifta servrar, datorer och fixa Officepaket och sånt och väldigt lite om att faktiskt förändra sättet vi arbetar på"*
Translated - "*It has become its own entity that is relatively disconnected from the actual construction operations. They are mostly operating servers, computers, fixing Office suites and stuff like that, and are doing very little regarding actually changing the way we work*"

____________________________Quote 23 - R4__________________________________

Original - *"Parallellt med detta [BIM] har det legat en process med ritningshantering som vi inte har gått ifrån, utan den juridiska handlingen är fortfarande dokumentet och inte modellen"*

Translated - "*In parallel with this [BIM], there has been a process centered on drawings which we haven't moved past. The legal document is still the drawing and not the model"*

____________________________Quote 24 - R19_________________________________

Original - *". . .det ju så att man aldrig litar på modellen fullt ut och man vill alltid ha ritningarna att gå tillbaka till för det känns tryggare. Så modellen har varit något man haft på sidan om och aldrig riktigt byggt efter"*

Translated - "*. . .people have never fully trusted the model and still want to be able to go back to the drawings because it feels safer. So the model has been something that has been on the side and has never really been built according to*"

____________________________Quote 25 - R6__________________________________

Original - *"Man tror ofta att BIM är dyrt, men det beror på att vi inte gör oss av med de gamla arbetssätten, så det är en falsk uppfattning. Vi måste istället börja på ett vitt papper och tänka hur skulle processen se ut med bara BIM och göra det"*

Translated - *"It's a general belief that BIM is expensive, the reason being that we never fully get rid of the old methods, so it's a false perception. We have to start on a blank slate and imagine how the process would look like with only BIM, and do that instead"*

____________________________Quote 26 - R6__________________________________

Original - *". . man säger att det ska typ vara en dörr här eller typ ett fönster här, det syns ofta på tester med laserskanning och fotogrammetrin att slutprodukten ofta inte alls stämmer överens med planerna. Kan man inte projektera mer specifikt, vad är poängen med AR?"*

Translated - *". . .saying that is supposed to be 'roughly a door' or 'a type of window' is not enough. It's often visible at laser scanning and photogram measurement that the result does not line up according to the plans. If you cannot design more specifically, what's the point with AR?"*

____________________________Quote 27 - R15_________________________________

Original - *"Grejen med varför man inte har exakta objekt från början är ju att man inte vet exakt vilken produkt man vill ha, det kan ta 6 månader med upphandlingarna och det handlar om många aspekter"*

Translated - *"The reason why we don't use precise objects from the beginning is that you do not know exactly which product you need, it can take up to 6 months with procurements, and there is a lot of aspects to consider"*

____________________________Quote 28 - R11_________________________________

Original - *"Om man idag lägger två samordningsmodellen bredvid varandra så ser man att man använt två helt olika arbetssätt, så kan vi inte ha det"*

Translated - *"Today, if you put two coordination models next to each other, you'll see that two completely different ways of working has been used, we can't have it like that"*

Quote 29 - R7

Original - *"MMI visar de krav för vilken mognad som BIM modellen skall ha i olika skeden. Räcker det ex. i projekteringsskedet att detta är en fyrkant eller ska det i en bygghandling stå att den är uppbyggd av olika delar?"*

Translated - *"MMI shows the maturity requirements that the BIM model should have at different stages, i.e. is it enough that something in the design phase is displayed as a square, or does it have to be written in a construction document that it's made up of different parts?"*

Quote 30 - R5

Original - *"Koordinat-trackingen är det som behöver fixas, det är den stora puckeln man måste komma över. Fixar man det så finns det nämligen inget som säger emot tekniken, allt annat kan hanteras och kommer att hanteras så småningom"*

Translated - *"The coordinate tracking is what needs to be fixed; it's the great obstacle we need to get over. If it's fixed, there is nothing that speaks against the technology, everything else can be managed and will be managed eventually"*

Quote 31 - R12

Original - *". . . man har ingen referens var man är, den är bara bunden till massa punkter och inte till en geografisk position. Med GPS kan man ta en modell, ladda upp den direkt och då är den på rätt plats rent geografisk"*

Translated - *". . .you have no real reference where you are, it's bound to points instead of a geographical position. With GPS you can take a model, upload it, and then it's geographically in the right place"*

Quote 32 - R14

Original - *"GPS kommer nog definitivt ha sin plats under en kortare tid men det blir intressant när man kombinerar med 5G för då får man felkorrigering så du tar bort felet från den ena med hjälp av den andra"*

Translated - *"GPS will most definitely have its place, but what's really interesting is when it's combined with 5G, then you get an error correction as one removes the error from the other"*

Quote 33 - R18

Orginal - *"Det du får göra då är att jobba med markörer, det är så alla löser det! Det blir som punkter att fixa sig vid som får AR att göra vissa saker ex. ta upp ett visst hologram"*

Translated - *"What you need to do is to use markers, that's how everyone solves it! It's like points to which the AR can position itself and makes it do certain things, like showing a hologram"*

Quote 34 - R7

Original - *"Då tappar man ju hela grejen! Ska vi få ut det till hantverkarna så kan de ju inte släpa på en extra verktygsväska för att få uppkoppling till sina brillor, då blir det svårt att motivera nyttan"*

Translated - *"Then you lose the whole thing! We can't expect the craftsmen to carry an extra tool bag just to get connection to their glasses, or it's going to be hard to motivate the practicality"*

Quote 35 - R14

Original - *"Vi förenklar geometrier och döljer de bitar som du för tillfället inte vill titta på, så vi filtrerar bort mycket data som inte är relevant för användaren att se för att kunna få AR att klara av att visa det"*

Translated - *"We simplify geometries and hide the pieces that are not needed, so in order for AR-glasses to manage to display the models we filter out lots of data that is not relevant for the user to see"*

Quote 36 - R14

Original - *"Det finns olika tekniker för att visa AR och en sådan är streaming, dvs. att man har en stark dator på distans som streamar video innehållet till AR, detta är väldigt lovande"*

Translated - *"There exists different technologies for displaying AR, and one such is streaming i.e. that you have a powerful computer remotely streaming the video content to AR, it's very promising"*

Quote 37 - R7

Original - *"Vi har ingen uppkoppling på bygget idag, eller vi har ju i boden, men så fort man går ut är det inget. Det har att göra med med att vi har ju ingen teknik på byggarbetsplatser som behöver vara ständigt uppkopplad idag"*

Translated - *"We have no network connection at the [construction] site today, well we do in the barracks, but as soon as you leave it's nothing. This has to do with the fact that there is no technology in need of constant connection today"*

Quote 38 - R7

Original - *"Olika industrier har olika behov av tekniken så byggbranschen måste vara drivande för våra specifika behov i teknikutvecklingen"*

Translated - *"Different industries have different technology requirements, so the construction industry must push for our specific needs in technology development"*

Quote 39 - R13

Original - "Jag tycker att rena uppsägelsen att byggföretag faktiskt testat detta och att byggarbetare varit villiga att ta med glasögonen på en byggarbetsplats som en extra device är väldigt intressant"

Translated - *"The pure realization that construction companies actually tests this, and has been willing to bring AR glasses to a construction site as an additional device is really interesting"*

Quote 40 - R20

Original - *"Vi tittade själva närmare på vilka möjligheter som skulle finnas för att integrera våra teknologier på byggarbetsplatsen, de är stora. Dock har intresset varit ganska svagt från branschen. Hoppas trenden vänder genom ert arbete"*

Translated - *"We investigated the opportunities to integrate our technology at the construction site ourselves, and they are large. However, interest has been quite weak from the industry"*

Quote 41 - R13

Original - *“Märker man att det blir ett intresse och en ‘pull effekt’ istället för att vi som utvecklare måste ‘pusha’ på byggbranschen så blir det väldigt intressant, då kan det verkligen vara en bjässe som håller på att vakna”*

Translated - *“If you notice an interest and a pull-effect, instead that we as developers has to push the construction industry, it becomes very interesting, then it can really be a giant starting to wake up”*

Quote 42 - R8

Original - “Jag vill verkligen se värdet med det innan man drar igång en större digitalisering”

Translate - *“I really what to see the value before committing to a larger digitalization”*

Quote 43 - R13

Original - *“Man har inte förankrat det tillräckligt bra, det blir som att arbetarna får se mellan raderna; att ni ska göra så här men på samma gång sköta ert vanliga jobb, vad är det då som man prioriterar?”*

Translated - *“It has not been anchored well enough, and the workers have to read between the lines; you need to do the new things in addition to your usual job, then what gets the priority?”*

Quote 44 - R4

Original - *“AR på bygg kan lösa befintliga problem med att titta på modellen. Men det här kommer ta tid, det är inte de tekniska lösningarna som kommer frälsa byggarbetarna utan man får föregå med allt från pilotprojekt till testprojekt, och låta det goda exemplet leda vägen”*

Translated - *“AR in construction can solve existing problems associated with looking at the model. But it will take time, it’s not the technical solutions that will convince the workers, instead we have to precede with everything from pilot- and test projects and let the good example lead the way”*

Quote 45 - R10

Original - *“Byggarbetarna tyckte det var ‘svin-intressant’, och när vi dessutom visade detta så såg personer från andra områden [än armering] att så skulle de också vilja jobba, så ryktet spreds och nu har vi sex stycken pilotprojekt”*

Translated - *“The construction workers thought it was really interesting, additionally, when we showed it; personnel from other areas [than reinforcement] discovered that they also would like to work with it, so the reputation spread and now we have six pilot projects”*

Quote 46 - R4

Original - *“Det finns ju en risk att få för mycket information, till skillnad från de traditionella handlingarna då man får en sak i taget”*

Translated - *“There is a risk of getting too much information, unlike traditional documents where there is one thing at a time”*

___________________________Quote 47 - R4___________________________________

Original - *". . . möjligheten det finns att lyfta fram information måste ske på ett delikat sätt så att det inte blir för mycket. Då det inte handlar om att ge mycket, utan rätt information. Det handlar inte om att få en hel informationsmodell på en skärm utan att få rätt information som stöd för en viss process"*

Translated - *". . . the possibility to bring forth information must be done in a delicate way, so that it does not get out of hand. Since it's not about giving much, but the right information. It's not about getting an entire information model on a screen, but instead getting the right information to support a particular process"*

___________________________Quote 48 - R10__________________________________

Original - *"vi började från ingenting och tagit fram allt specifikt för ett visst moment"*

Translated - *"We started from nothing and developed everything for a particular operation"*

Appendix 4 – Workshop guide

Background

The background for the workshop is to test the findings in a more practical setting. The university will confirm the academic side of the report, and we need your help to examine the practical side. We are striving for an even balance between both.

We have found several dimensions, barriers, and practical measures that need to be presented in an intuitive way for the users. We will show and explain these to you, and you can ask any related questions regarding, for instance, their relevance. Feel free to discuss among each other. When you understand the findings, we will start discussing your thoughts regarding how these can be presented. We prefer to hold the discussion open, rather than meticulously steering it.

Participants

Position / Title	Company
Author	Luleå University of Technology
Author	Luleå University of Technology
Head of Digital operations	Large construction company
Product Owner Model based processes	Large construction company
BIM Strategist	Large construction company

Purpose

The objective of the workshop is to develop a roadmap for implementation of BIM through AR that is useful in a practical setting. The purpose of the map is to guide construction companies towards an implementation by illustrating the present state of the construction industry and AR technology, highlight challenging areas as well as informing construction companies regarding measures that need to be taken to facilitate an implementation.

- Do you find the result useful for the construction industry?
    - Is there anything you are skeptical to?
    - Is anything missing?
- In which setting do you see construction companies using the result?
- How would you like our finding to be presented to increase the usability?

Goal

1. That you understand the result and learn something new
2. If not, provide guidance regarding improvements
3. The baseline for a visualization that is useful in an industry setting is developed

Appendix 5 – Representative Quotes and Underlying Themes

Second order theme	First order theme	Representative quote
Increased spatial cognition	Easier to explain	Q1
	Get a common picture	Q2
Increased Information flow	Much information	Q3
	Up to date information	Q4
	Consistent information flow	Q5
	Business intelligence	Q6
Emancipated Resources	Non-value-creating work	Q7
	Lean processes	Q8
Internal cooperation	Over-the-wall communication	Q9
	Lack of support	Q10
	Duplication of efforts	Q11
External cooperation	Cooperation and competition	Q12, Q13
	Emerging disrupters	Q14
Conduct pilot tests	Process innovation	Q15
	Outlining requirements	Q16
Anchor in vision/strategy	Listen to users	Q17
	Lacking feedback	Q18
	Establish business cases	Q19
Allocate staff	Not enough resources	Q20, Q21
	Disconnected departments	Q22
Raise the status of BIM	Low status of BIM	Q23, Q24
	Old way of working	Q25
Develop Model Maturity Index	Imprecise design	Q26
	Required flexibility	Q27
	Standardized working methods	Q28
	Control documents	Q29
New positioning technology	Positioning precision	Q30
	Geographical positioning	Q31, Q33
	Position improvements	Q32
Simplify the models	Weight and size limitations	Q34
	Simplify geometries	Q35
Cloud computing	New computing technology	Q36
	Network connection	Q37
Active role in development	Drive the development	Q38
	Low awareness	Q39, Q40
	Drive the development	Q41
Organic dispersion	Show value	Q42, Q44
	Anchor the technology	Q43
	Leverage interest	Q45
Develop for a specific area	More access to information	Q46
	Prioritize information	Q47
	Start small	Q48

Appendix 6 – Roadmap