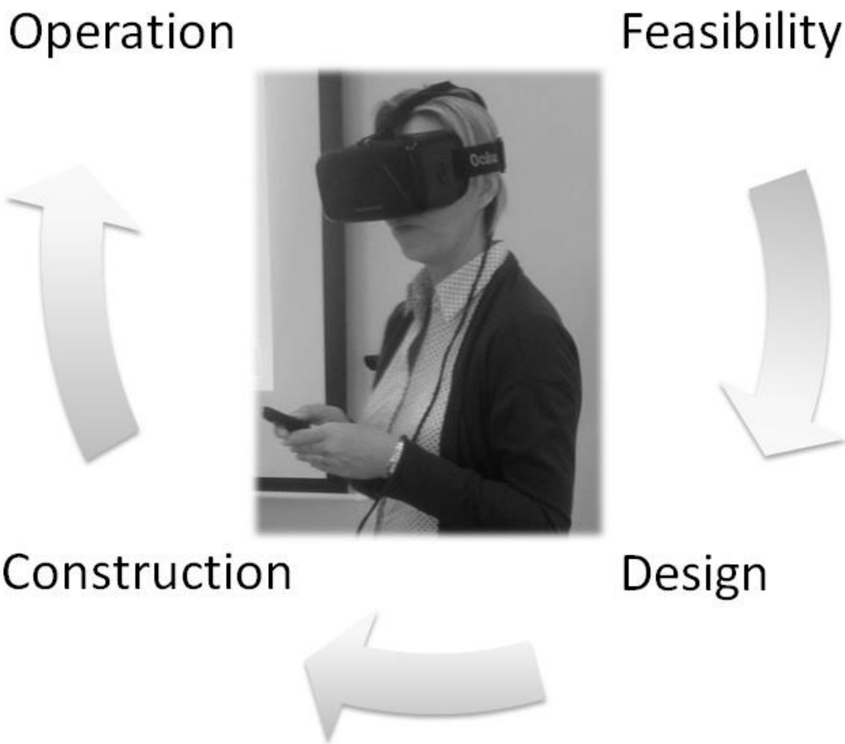

The BIM Head Mounted Display as an integrative part of project phases

A case study of applying new technologies in a construction project

Master's Thesis in the Master's Programme Design and Construction Project Management

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Department of Civil and Environmental Engineering
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Cover:
Picture - Interviewee testing the BIM Head Mounted Display. Source: the authors.

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ABSTRACT

BIM technologies have contributed with many applications aiming to address the fragmented nature of the construction industry (Eastman, 2011). As an example, BIM visualizations are supporting better collaborations and communication overall, facilitating a common understanding between the different project disciplines (Azhar et al., 2012). Current research has made possible the use of a head mounted display to experience the building information model in an immersive environment. Considering its accessibility and the new way to experience the building environment, the possibilities of use are still yet to be explored (Johansson et al., 2014).

The purpose of this thesis is to examine how the tool BIM Head mounted display can be applied in a construction project. In addition to recent research considering this technology (Johansson et al., 2014), the focus extends on all project phases: feasibility, design, construction and operation. Delimitations consider a single case study with a number of nine interviews and group observations. In addition, limited focus has been on the implementation of the technology in the long term perspective.

The results show differences among disciplines, considering how building information model is used during daily working procedures. Consequently, virtual models have been used only in the design and construction phases. However, the BIM Head mounted display could benefit each discipline considering all four phases. Possible applications such as property marketing, job planning, design iterations and safety operations are supported by the findings. Overall, the tool can support decision making and a better understanding of the building process, especially for clients or /and users. To accomplish the aforementioned, drawbacks, future technical developments and organisational actions are necessary.

This study confirms that communication barriers are similar with early research. The social aspects in construction projects need to be considered, as the tool only should be seen as a complement within the communication process. Clear intentions are necessary when the technique is used by people with less knowledge, in order to limit wrong expectations of the end product. Finally, the application of a new technology needs to be stated by the main organisation to create clear responsibilities among project participants.

Keywords: construction projects, communication, BIM, immersive virtual reality

BIM Huvudmonterad skärm som integrerad del av ett projekts faser
En fallstudie gällande tillämpning av ny teknik i ett byggnadsprojekt

Examensarbete inom masterprogrammet Design and Construction Project Management

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SAMMANFATTNING

Teknologi avseende Byggnadsinformationsmodeller (BIM) har bidragit med flera tillämpningsområden i syfte att förbättra byggprojekt vilka anses vara alltför fragmenterade (Eastman, 2011). Visualisering av BIM bidrar till bättre samarbete och till en bättre kommunikation i sin helhet, där visualisering underlättar en gemensam förståelse mellan olika discipliner (Azhar et al., 2012). Forskning presenterad nyligen har undersökt möjliga tillämpningar av tekniken huvudmonterad skärm, avseende visualisering av BIM i en mer omslutande virtuell miljö. Tillgängligheten av denna teknik gör det möjligt att visulisera byggnader och dess miljöer på helt nya sätt. Men hur denna teknik kan användas behöver vidare utforskas (Johansson et al., 2014).

Syftet med detta examensarbete är att undersöka hur tekniken BIM Huvudmonterad skärm kan tillämpas i ett byggnadsprojekt. Utöver tidigare forskning gjord om denna teknik (Johansson et al., 2014), har denna studie berört ett byggprojekts alla fyra faser: förstudie, projektering, produktion och operation/drift. Studien är avgränsad till en fallstudie där intervjuade personer endast använt tekniken under en begränsad tid. Vidare är studien avgränsad avseende vad som krävs för slutlig implementering, där denna studie endast haft ett generellt perspektiv.

Resultatet visar på olikheter bland discipliner till vilken grad Byggnadsinformations-modeller används som del av det dagliga arbetssättet. Följaktligen, virtuella modeller har endast använts inom projektering samt under produktion. Huvudmonterad skärm har visat sig vara fördelaktig för vardera disciplinen inom samtliga projektfaser. Möjliga tillämpningar inom marknadsföring, projekteringsändringar, arbets-beredningar och räddningsinsatser stöds av resultatet. Denna teknik kan stödja beslutsprocessen och bidra med en bättre förståelse av byggprocessen, speciellt för kunder och/eller brukare. För att uppnå det ovan nämnda, behövs ytterligare teknisk utveckling, samt att nackdelar och förslag på åtgärder inom organisationen beaktas.

Denna studie bekräftar flertalet barriärer vid kommunikation som visats av tidigare forskning. Hänsyn måste tas till de sociala aspekterna inom byggnadsprojekt, där denna teknik endast bör ses som ett komplement inom kommunikationsprocessen. Tydliga intentioner behöver finnas när tekniken används av personer med en mindre kunskapsnivå, i syfte att skapa rätt förväntningar om slutprodukten. Slutligen, vid tillämpning av ny teknik behöver ansvariga inom organisationen vara tydligt anvisade.

Nyckelord: byggnadsprojekt, kommunikation, BIM, omslutande virtuell miljö

Contents

Preface

This Master of Science thesis is the final project within the studies at the Department of Civil and Environmental Engineering at Chalmers University of Technology. It is based on a case study, conducted in collaboration with NCC Construction in Gothenburg during the spring 2015.

Several persons have been of support throughout this study. Both our supervisors from the university, Mattias Roupé and Mikael Johansson have been of great help in the formulation of the research questions, as well as in providing the necessary technical support. The collaboration with our supervisor at NCC, Per Öberg, has been of importance, assisting this thesis with a suitable case project and further giving advice regarding its disposition. We would like to thank all project participants that have been part of this study. The full engagement even within a short timeframe has been much appreciated.

Gothenburg, June 2015

Fredrik Jörnebrant and Petru Andrei Tomsa

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1 Introduction

This chapter presents the background within the construction industry and explains the underlying problems regarding communication. Within the background the development regarding virtual visualisations are described which initiated the purpose for this study. In addition, four research questions are presented followed by its delimitations.

1.1 Background

Construction is often referred as a project based industry where different disciplines collaborate for a specific time, in remote locations and within the constraints of time, cost and performance. Each project is characterized by complexities in terms of size, actors involved, site location and other variables which require different approaches to be managed (Maylor, 2010). Even when standardized projects are employed, there will still be considerations in terms how the different actors work and understand each other, their behaviours and relationships. This is highly important considering that the industry is one of the most people-reliant, ranging from unskilled and craft to managerial and administrative work force. Furthermore, these individuals may represent different organisations and have own objectives, working culture as well as different understanding of the technical language, which can lead to misunderstandings, disputes and adversarial behaviour (Dainty et al., 2006). Consequently, these characteristics give a picture of the fragmented nature of construction.

Therefore, the way information is communicated and understood is essential for fulfilling a project's objectives. The emphasis on communication should be considered at the core of all processes involving people and their activities. Hence, many construction companies recognize that effective communication is a key for staying competitive on the construction market. Despite knowing this, a lack of clear objectives, faulty transmission, and distorted information together with other technological barriers still hinder effective communication (Dainty et al., 2006).

The advancement of Information Technology in the form of BIM has changed the way the Architectural Engineering Construction (AEC) industry work, facilitating faster processes and more effective collaborations (Henderson and Ruikar, 2010). A constant transition from the traditional way of working e.g. with 2D drawings is moving towards Building Information Modelling (BIM), where all project information can be easily accessed and updated by the different parties (Eastman, 2011). The benefits of BIM have been proven by applications such as option analysis, information take-off, visualizations etc., whereas some construction companies have already adopted BIM as an internal requirement with their projects (Azhar et al., 2012).

One of the biggest advantages with BIM is model visualizations. By visualizing the virtual reality (VR) model of a construction, the different parties can communicate around a common point of reference while having the visual cues to support their understanding (Azhar et al., 2012). This can allow the creative expression of ideas and problem solving, with a faster decision-making and information exchange. The possibilities of using VR visualizations in construction projects can be a further step to reshape the interaction between its users and the computer (Ye et al., 2006). While the most common use of VR visualizations are in the context of non-immersive environments using computer displays, higher levels of immersion present a better level of realism, sense of scale and the feeling of being 'present' in the virtual environment (Johansson et al., 2014). Compared with the traditional representational mediums such as drawings and scaled models, the immersive VR (IVR) can eliminate the additional need to visualize the space and movement through it (Castronovo et al., 2013). Further, IVR can allow the interaction with the 3D model to create and modify directly shapes, objects, colours at a human scale (Dolinsky et al., 2014). This may also be considered as a medium of communication using virtual walkthroughs with clients trying different designs (Bouchlaghem et al., 2005). The uses of IVR have been also explored in construction safety training where it showed to be a more engaging way of learning and identifying risks than traditional methods (Sacks et al., 2013). As the applications of IVR are positively perceived by construction professionals, often special designed facilities are necessary, together with equipment, training and associated costs. This puts into question the feasibility of its uses.

Growing BIM use and technological advancement provides an accessible way to overpass the aforementioned barriers. Adopting a gaming technology to the construction sector, the Head Mounted Display allows immersive visualizations compatible with BIM software. Using this technology, Johansson et al. (2014) developed a portable system which allows immersive BIM visualizations, eliminating the aforementioned barriers. This can be easily used in the context of design reviews and client visualizations without the need to travel to a specific location. Considering the accessibility of the interface, the possibilities of use are still to be explored in different contexts. There are few if any limitations that impede the BIM Head Mounted Display (BIM HMD) to become an integrative part of construction projects.

1.2 Purpose and research questions

The purpose of this thesis is to examine how the tool BIM HMD can be applied in construction projects. By looking into all the phases of a construction project, the feasibility of the tool as a medium of communication is analysed. More specifically, this thesis tries to answer the following research questions:

- How can the visualisation tool BIM Head mounted display be used as a medium of communication in a construction projects?
- What are the possible applications in the different phases: feasibility, design, construction and operations?
- Does the use of BIM Head mounted display bring any benefits or challenges?
- What is required within a project based organisation to implement new technologies?

1.3 Delimitations

Recent studies have been focused on using the head mounted display (HMD) system only in the construction phase (Johansson et al., 2014). Even so, there is limited literature involving the uses of a head mounted display in construction projects. In addition to Johansson et al. (2014), this study focuses on a project's four phases.

The data gathered in order to answer the research questions is limited to one case project within the construction sector, where the HMD system is planned to be applied, see sub chapter 3.1.2. This system has only been applied in the design phase. Therefore, its natural use within feasibility, construction and operation has been limited and in several cases none. Considering this, all disciplines involved in this study have got the opportunity to test the tool in order to share their opinions regarding possible applications. The trial of the HMD was limited to a specific technical system with the use of two virtual models, see sub chapter 3.2.1.

Lastly, this study also examines what is required within a project based organisation to implement new technologies. Interviewed disciplines have shared their knowledge with its focus from an organisational perspective. However, change theory has not been considered in the theoretical framework. Last, delimitations are also emphasised in the discussion to indicate possible areas of future research.

2 Theoretical Background

This chapter presents the theoretical background which contributed to the development of the research questions. The theory has been selected to support the later empirical study. First, it considers the characteristics of the construction industry, examining theories and models of communication. Second the implementation of new technologies and their requirements and common barriers. Last, the concept of BIM and IVR visualizations.

2.1 Construction industry

Companies within construction industry have mostly a project based organisational structure. According to Maylor (2010), whole sectors of industry are project based organisations, where projects are described to be the fundamental way for companies to operate and create their revenues. Construction alone stands for 8 per cent of gross domestic product in the European Union where projects are central to the economy. Bower (2010) also describes the construction industry as playing an important role in the economic development and refers to construction in UK, where the sector generates roughly 10 per cent of the country's annual gross domestic product, numbers based on data from Construction Task Force, 1998.

The construction industry should be not seen as a single industry but instead as consisting of several different market areas (Bower, 2010). The different size, type, project location and level of complexity decide where companies have their market areas, and in some cases they are overlapping each other and creating a competitive environment. The construction sector has been facing high level of turbulence according to rapid advances and complexity in technology. This new environment is explained to break down traditional barriers between industries which in turn, affect how companies look at their position on the market. Due to this, the development of business strategies has become more important where new business relationships and long-term customer loyalty are in focus.

2.1.1 Customer value through project phases

Business strategies as the creation of long-term customer loyalty has become more common within the construction industry, where companies within the construction industry adapt philosophies from manufacturer industry such as e.g. lean production or lean construction (Shang and Low, 2014). Companies start to see the importance of long term relationships as a competitive advantage.

According to Bower (2010), a project can be seen as a whole chain of value, where the different project phases contribute with even more value to the customer. When narrowing the project value chain to consider the construction industry, corporate value and business value will not be included in the individual project value chain. Project phases that contribute with value are: Feasibility value, Design value and Construction value. The last is the Operational value, which is the subsequent phase, though not part of the individual project value.

Shang and Low (2014) describe owner involvement as being higher in construction industry, compared to the manufacturing industry. Regarding owner involvement, defining customer value has been questioned when it is applied to construction. Several issues are brought up considering customer value in relation to the project life cycle. First, construction is a long-term investment and it is designed to function for one hundred years or more. Second, the number of different owners and users will have different interests and perceptions on value. Even the project definition may vary during its life cycle, which is an outcome of different interest groups involved in different project stages. Finally, the level of complexities increases when the concept of value is discussed in the field of architectural design, where issues in more details must be taken into consideration.

2.2 Communication

The scope of communication is wide and comprehensive (Rayudu, 2010). Communication is a two-way process involving both transmission and reception, compared with e.g. downward movement of sending directions, orders, instructions, which is not. Two-way communication can be represented by internal flows in different directions such as vertical, horizontal, diagonal and across the organisational structure. Communication can be seen as an almost unlimited dimension and as interdisciplinary. In addition to this, Dainty et al. (2006) explain communication as multidimensional and actually an unclear concept where it can have a variety of different meanings, contexts, forms and impact, which means different things for various people in different situations.

Yeger (2015) describes communication as being developed from rather primitive ages, but effective methods during the years led to today's highly sophisticated internet modalities. Similar to this, Dainty et al. (2006) describes the development of communication and refers back to the years 1950s and 1960s. Research at this time emphasised face-to-face interaction as the primary method of communication within organisations. Today, Information and Communication Technology (ICT) shapes many of the industry's design and production functions, and also has significant impact on the operations of finished buildings. According to Dainty et al. (2006), ICT is necessary for delivering efficiency and improving project performance in the construction industry. However, the development of ICT should not be considered as one single solution. The profile of human communication is still emphasised as the crucial enabler for industry improvement. The reason is that ICT is just supporting some parts of the elements involved within the concepts of communication.

2.2.1 Communication as a process

There are various definitions describing the main concept of communication. Rayudu (2010) have reviewed definitions stated from fifteen different researchers, where one of these is defined as:

Communication is an exchange of facts, ideas, opinions, or emotions by two or more persons. Communication is also defined as intercourse by words, letters, symbols, or messages and as a way that one organisation member shares meaning and understanding with another.

The sequence within the communication process regarding receiving messages is described by Rayudu (2010) as: interprets, perceives and responds to it. Regarding the definition, this process should not be seen as a linear process. When one person transmits the facts, ideas, opinions or feelings, the second person responds by communicating facts, ideas, feelings or attitudes. The fact that the person responds to the other creates the conditions to be considered as a circular process.

2.2.2 Communication theory

Several models and theories have been developed by various scientists where these theories combined contribute to understand the process of communication (Rayudu, 2010). The first model within this area of theory was the *linear model* by Aristotle which is described as simple and elementary, from speaker to the audience. Regarding the development of technical aspects of communication, *mathematical theory* was developed in 1949 by engineers where focus was put on measuring information transmitted over the technical channel.

David k. Berlo's Model is a third model which is described to be one of the basic theories for all communication theorists (Rayudu, 2010). The model based on nine components (see Figure 1), differ in comparison to previous reviewed theories where this is a "circular" model. Feedback makes the process of communication circular and is presented as the most important element of communication. Effective communication is described as circular in nature, where feedback create the interaction between the sender and the receiver, and moreover create the conditions to measure and evaluate the message received which develops future communication.

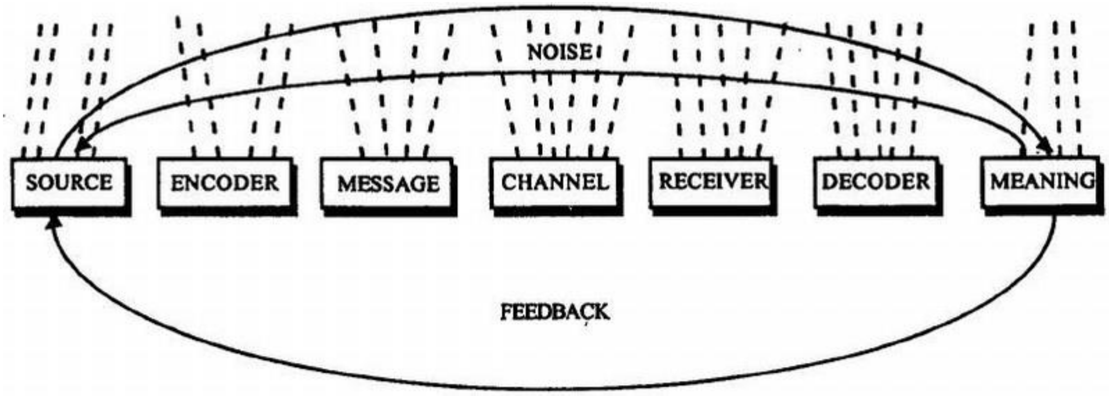

Figure 1 David k. Berlo's Model (Rayudu, C.S., (2010)

In addition to David k. Berlo's Model, Dainty et al. (2006) describes the process of communication as: *Encode*, *Transmit*, *Decode* and *Interpret*, where *Transmit* is equally to the channel (see Figure 1). As was previously stated, the development of ICT should not be considered as one single solution. The reason is that ICT only consider some parts within the process of communication. However, recent research (Roupé, 2013) has showed that new technology may help to even receive and decode information (see sub chapter 2.6.1). Still, ICT cannot support the whole communication process. Therefore, it is necessary to consider the human and social aspects within the area of communication, and especially within construction projects.

2.3 Social aspects in construction projects

It is essential to view construction as a social activity. Construction projects draw together individuals from a range of disciplines together with an equally diverse selection of sub-contractors (Gomez, 2006). Additionally, Schaufelberger and Holm (2002) see construction projects as teams of people representing many organisations and describe that relationships with bad character have historically resulted in costly disputes and litigations. Moreover, the organisational structure as a project based industry tends to be characterised by unfamiliar groups of people coming together for short periods before dissolving to work on others (Dainty et al., 2006). These temporal organisations complicate an already problematic environment, especially affecting how people communicate. In fact, these projects involve multiple organisations working in an interdisciplinary environment, meaning that organisational units cross traditional boundaries. Finally, technical language, an adversarial culture and noise/distraction are presented, inhibiting straightforward information flows between project participants.

2.3.1 Person's individual interpretations

The construction environment, characterized by noise in addition with its technical language and various frames of reference that exist within different processes, increase the risk of interpretations (Dainty et al., 2006). Moreover, the personal perspective or perceptions and a person's individual frame of reference will affect the person's interpretations. Actually, different perspectives lead in turn to different conclusions (Mezher et al., 1998). This awareness regarding individual interpretations is important to have and was early emphasised above in the process of communication and the stage of perceiving and interpreting the transmitted information.

2.3.2 Barriers for common understanding

Due to different professional roles that exist within the sector, it is especially important to overcome communication barriers (Dainty et al., 2006). One of the barriers is described as differences in languages, the so called jargon used by different professionals which affects the interpretations between parties. The barriers presented to decrease the level of efficient communication and common understanding are: (1) the individual's frame of reference, (2) stereotyping, (3) cognitive dissonance (the state of having inconsistent thoughts, beliefs or attitudes), (4) 'Halo or Horns effect (cognitive bias), and lastly (5) people not paying attention. Below, five areas of barriers are presented further:

1. A lack of clear objectives - Without a clear intention, this leads to uncertainty of the message and to confusion between the transmitter and receiver.

2. Faulty transmission - Usually occurs because the message is sent via an inappropriate medium or channel. It can also occur when a receiver is expected to absorb too much information or when they lack an insight into the circumstances around the transmission.

3. Perception and attitude problems - Are related to misunderstood messages where transmitter and receiver attribute different meanings so that a shared understanding is not possible.

4. Environmental problems - From distractions and noise, a lack of appropriate communications media and physical distance.

5. Chinese Whisper - The phenomenon of a message being gradually distorted as it passes along the message chain. The longer the chain, the more distorted the message would become.

2.3.3 Decision making process

Decision-making is considered as part of a generic problem solving process, where the process is part of the social environment (Maylor, 2010). The social aspects within the process of decisions come from how people are affected by taken decisions. As an example, risky decisions may affect people to feel better, even when the decision itself is based on uncertainty and inadequate knowledge (Maylor, 2010). Regarding problem-solving, it is common that people enter discussions with solutions in mind rather than the analysis of the problem itself. The analysis of most alternative choice problems involves five steps, according to Anthony et al. (2011) as follows:

1. Define the problem;
2. Select possible alternative solutions;
3. For each selected alternative, measure and evaluate those consequences that can be expressed in quantitative terms;
4. Identify those consequences that cannot be expressed in quantitative terms and evaluate them against each other and against the measured consequences;
5. Reach a decision.

According to Weijermars (2012), people are said to be limited rationalist meaning that people tend to look for a limited number of alternatives, especially under time pressure. Many complex decisions in organisations are made by groups of people. Though, groups can sometimes produce inadequate solutions to problems, and because of that it is important to consider the average expertise. Regarding limited rational decisions, neuroscience research has emphasised the strong link between humans' decisions to peoples' emotions. As a matter of fact, decision-making takes place by emotionally motivated processes within each individual. Considering this, decision-making by humans is done because people feel motivated and rewarded to do so.

Explained by Weijermars (2012), certain tools and methods can be used to optimize decisions. However, the actual decision will still be based on emotions. Unhappy people tend to take decisions that are excessive motivated by personal displeasure. On the other hand, happy people make decisions that are less self-centred and more properly accounted for stakeholder expectations. Finally, these kinds of people are positively engaged with their internal emotions and motivated to follow the company's goals, regarding ethical guidelines, sustainable vision, and values.

Next chapter will consider new technologies developed during the lately years, with its purpose to decrease the aforementioned communication barriers and to support the communication process including decision-making within construction projects.

2.4 New technology implementation

The implementation of a new technology can be a complex process considering the fragmented nature of the construction industry (Henderson and Ruikar, 2010). Over the years, the advancement of ICT has impacted in several positive ways how the different project participants work and get their jobs done. BIM applications and different document management systems created an easier way to access and modify information for all disciplines. These changes are continually happening and heading to new directions where BIM visualizations and Virtual Reality creates better understanding and collaborations (Froese, 2010). There are many examples that new technologies such as BIM applications, bring a competitive advantage for organisations but the implementation is often a slow multi-phased process (Azhar et al., 2012).

In order to implement a new technology it is important to know if the invested resources will reflect the investment. However, many times the barriers for implementation are related to changes in people's practices rather than technological problems of financial considerations (Henderson and Ruikar, 2010). To implement a new technology in a construction organisation, both the decision making and implementation process need to follow a transparent rationale, while involving the different levels of management (Henderson and Ruikar, 2010).

2.4.1 Decision to implement

The decision-making process can be attributed to the different levels of management considering senior, middle, lower and or a combination of levels (see Figure 2). The suitability of the decision maker considers variables such as size of investment, area of interest and impact on employees. It is more likely that a multi-level involvement of the different levels of management will affect the implementation decision-making, rather than an imposed top down procedure. This process creates a know why of the new introduced technology and reduces the potential barriers such as people’s resistance to change. Decisions taken in a top-down approach are less likely to be effective because employees have the tendency to reject something imposed. On the other hand, involvement and awareness reduces the level of uncertainty creating an understanding of the implementation process. According to Henderson and Ruikar (2010) the process of decision-making for the successful implementation of a technology presents the following:

- compatibility between decisions;
- decisions taken considering the perspective from all levels of management;
- rationale and transparency for the decisions;
- employee involvement in the process.

2.4.2 Implementation process

The implementation process evolves with the identification of a need, usually brought by lower or middle management. The need is then discussed with its initiator(s) to reach an agreement if there is the case. A following step considers potential solutions which are summarized as benefits and drawbacks. This ultimately results into a proposal to be assessed by senior management. If the presented proposal is found attractive from a business standpoint, often middle management is assigned to develop a full implementation strategy. Then, low levels of management are to carry out first trials at a smaller scale. Figure 2 illustrates this entire process.

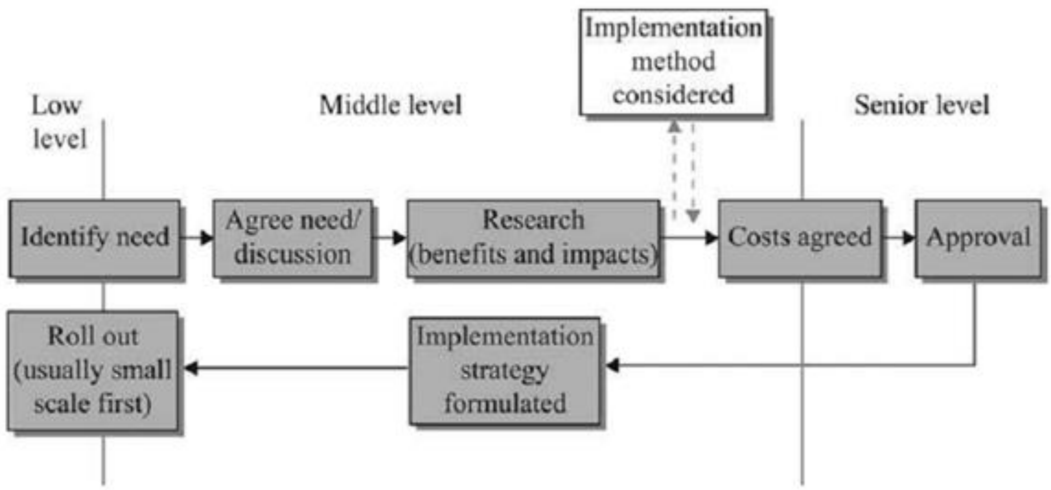

Figure 2 Implementation through an organisational hierarchy (Henderson and Ruikar, 2010).

2.4.3 Barriers for technology implementation

The barriers can be categorised according to project, organisation and industry level. At an industry level, among the most important barrier is the industry's competitive nature and the mixed knowledge areas of organisations. Small and medium size organizations have limited resources available for new technologies and are not as proactive as bigger organisations. This affects the industry as a whole due to unequal focus and knowledge sharing (Stewart et al., 2004). Moreover, Henderson and Ruikar (2010) points out that lack of leadership of client organisations and variations in workload activity levels are among the highest barriers. Further considering the organisational level, the reluctance of managers to invest and provide strategic planning for implementation is considered a big barrier. This can be explained to conservative practices but also because of the lack of tangible benefits and return of investment (Stewart et al., 2004). This is also agreed by Henderson and Ruikar (2010), which considers the resistance of staff to change as the highest barrier. From a project level perspective, the short duration of construction projects and their limited time frame makes it difficult to try new technologies. Also, the need of training and employees' comfort area to change their working practices can explain the low engagement of technologies uptake. Figure 3 summaries the most important barriers to implement a new technology at the different levels.

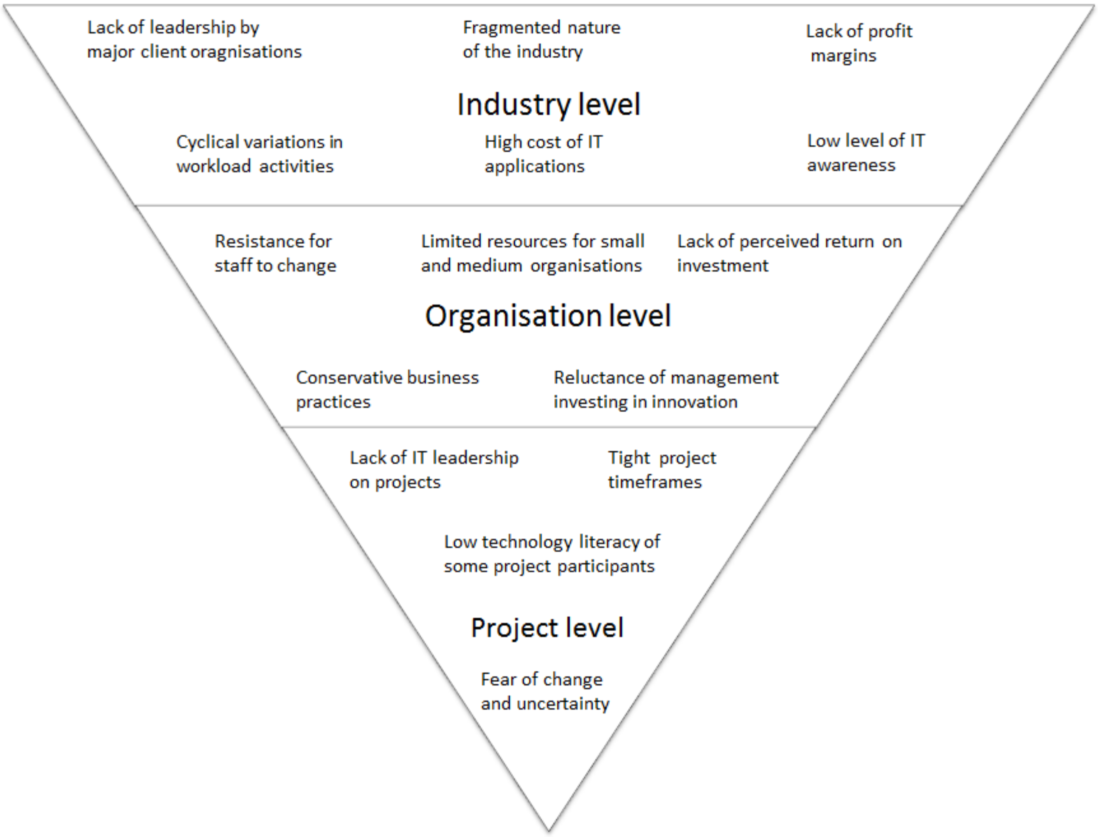

Figure 3 New technology implementation barriers. Adapted from Stewart et al. (2004) and Henderson and Ruikar (2010).

2.5 Building Information Modelling

Building Information Modelling (BIM) has become one of the most emerging technological developments in the Architecture Engineering Construction (AEC) industry. The interest with BIM comes as a need to improve processes, collaborations and information exchange during a project's life cycle, thus being a competitive advantage. Acknowledging this opportunity, the implementation of BIM has been on a continuous rise over the last decade (Eastman, 2011). As with most concepts, BIM has several interpretations and different definitions are present in the literature. According to the National Institute of Building Sciences (2007), BIM is defined as:

A building Information Model (BIM) is a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle from inception onward. A basic premise of BIM is collaboration by different stakeholders at different phases of the life cycle of a facility to insert, extract, update or modify information in the BIM process to support and reflect the roles of that stakeholder.

The definition implies that BIM is one source information software and also a process as it facilitates collaborations between stakeholders throughout the project (Azhar et al., 2012). It can be also interpreted as a human activity, since it has developed the way people work, creating new roles and responsibilities e.g. BIM coordinator (Eastman, 2011).

2.5.1 Levels of development

It is common that organizations have their own manual regarding how they work with BIM and its level of details. According to the BIM Guidelines, (2012) the build information model can be categorized according to the different levels of development (LOD), describing the cumulative level of details of a model, starting from conceptual design to the operation phase of a construction. Each LOD is aligned with one different phase in a construction project.

The first, LOD 100 (Pre-schematic) can describe building elements such as masses, to determine different areas and volumes of a building. LOD 200 (Schematic) is aligned with these masses, advancing to components which have thickness and width. At this stage quantity take-offs are possible. In LOD 300 (Design development) the components become assemblies, including material properties. Material take-offs together with different analysis such as energy, clash and cost can be performed. LOD 400 (Construction documents) provides complete information in terms of size, shape, location, quantity etc. At this level the model can have detailing information such as lengths and dimensions. LOD 500 (Service during construction) is the last level of development, with the model information ready to be constructed. At this stage the model can be also used for operations and maintenance services (BIM Guidelines, 2012).

2.5.2 BIM uses

The uses of BIM can be integrated during the whole life cycle of a facility, either by following a LOD system or having an in-house BIM approach. According to the requirements and goals, project stakeholders can chose a specific BIM use as the model develops. By BIM use it is understood the application of certain features as part of a process, usually according to the stage of the project BIM Guidelines, (2012). For example, the Design Review is the process where the 3D model may be analysed for design alternatives or constructability issues. There are a wide range of BIM uses that construction organisations may employ, some being used more than others. The most common ones are described in Table 1. According to Kreider et al. (2010), some of the most beneficial and frequent BIM uses by construction organisations are Design Reviews and 3D coordination. In addition, Azhar et al. (2012) points out that BIM visualizations are of the most common use for owners, designers, constructors and facility managers.

Table 1 Table 1 BIM process descriptions. BIM Guidelines, (2012)

BIM Use	Process Description
Existing Conditions Modelling	Process where the project team develops a 3D model of the existing condition of a facility.
Site Analysis	Properties in a given area evaluated to determine the most optimal site location
Programming	Assessment of the spatial requirements in terms of design performance.
Engineering Analysis	Associated BIM tools are used to conduct performance simulation for energy consumption of a facility during its life cycle.
Design Authoring	Process where the 3D model is connected to a set of database properties such as quantities, methods, costs and schedules
Sustainability (LEED) Evaluation	The BIM model is evaluated according to LEED criteria in terms of materials, performance, or a process.
Design review	The 3D model is used to analyse design alternatives and solve design and constructability issues.
Code Validation	A process where code validation software checks the model according to assigned building codes.
Clash Detection	Clash detection software is used during the coordination process to detect possible field conflicts between different 3D models.
Cost Estimation	Process where the BIM can be used to generate an accurate quantity, take-off and cost estimation.
Construction System Design	Process where the construction of a complex building system (form work, glazing, tie-backs) are designed and analysed.
Phase planning	The BIM is utilized to effectively plan and show the construction sequence and space requirements on a building site.
Digital Fabrication	A process that utilizes machine technology to prefabricate objects directly from a BIM
Record Modelling	Process to depict an accurate representation of the physical conditions, environment and assets of a facility.
Asset Management	This BIM use utilizes the data contained in a record model to determine the cost implications of changing or upgrading building assets.

2.6 Visualizations and Virtual Reality

Computer visualizations can be used throughout the whole life cycle of a construction project, allowing an iterative process for project participants as they advance their understanding. These are commonly used in architectural design, where sketches and 3D models allow architects to visualize their designs. Different scenarios can be evaluated by simulating interior design and conditions such as lighting, ventilation and acoustics (Bouchlaghem et al., 2005). Further development with building information modelling allowed the use of virtual reality for other design activities such model coordination and iterations (Woksepp and Olofsson, 2008).

Virtual Reality (VR) can be seen as a computer simulation of the real world where sensory systems adapt to the user movements giving the feeling of being present in the synthetic environment (Craig et al., 2009). The first start of VR is traced back in 1970, where flight simulators experiments were done using a head mounted display (HMD). Over time, several other applications in different industries have been explored. For example, in manufacturing virtual prototyping allowed the evaluation of products and machinery for better designs, whereas in medicine, it allowed the trial of complex experiments and operations. In the construction industry, VR has been identified as a useful tool with applications such as architectural walkthroughs, simulations and site monitoring, safety training and landscape design in urban planning. For example, site or architectural walkthroughs allow the user to navigate through an existing work site or building, experiencing a full scale model, while testing accessibility of doors, exits or positions of elements. Such an application can support a medium of communication between participants, allowing to share ideas and experiences (Craig et al., 2009).

According to Bouchlaghem et al. (2005), VR can be a helpful tool in the early phases of developing a project where there is a need of fast creation and evaluation of models. For example, in housing development, VR models proved to be useful for marketing purposes for prospective buyers, design development for site layouts and getting approvals of building permits. In other situations VR models helped project participants to better communicate and work more efficient. This is exemplified in the design reviews of a multi-disciplinary plant process project where VR models were used. By exploring different possibilities in a virtual environment, the design team could better understand the impact of the project as whole to provide the best solution for the client. The VR models helped to reduce the risk of misinterpretations and faster decision-making while exploring different design solutions and requirements. Moreover, going through the VR model and making modifications, the consequence of a decision could be seen more clearly on how it is influencing other disciplines (Woksepp and Olofsson, 2008).

With technological development the costs for adopting VR are becoming less and less, while the main barriers becomes from organisations and human attitudes (Bouchlaghem et al., 2005). Despite that the acceptance and credibility of VR models can be questionable at an early use, the scepticism decreases as the models become a natural part of people's daily work. According to Woksepp and Olofsson (2008), it is believed that VR models will be used more often in the future in designing, planning and process simulation.

2.6.1 Immersive Virtual Reality

Immersion can be an integrative feature of virtual reality. Different characteristics such as model complexity, display resolution and head-tracking can be used in three broad levels of immersion: non-immersive, semi-immersive and fully immersive (Castronovo et al., 2013). The most typical is the non-immersive systems which involves visualizations on a computer display or slide projections (Roupé, 2013). In this situation, it is common that the VR model is projected on a wall where project participants can navigate through a model, analysing different solutions and ideas. Semi-immersive extends the level of immersion by projecting the image on large, multiple screens, referred as Panoramas. The highest level of immersion is obtained by using systems such as a head mounted display or CAVE (Cave Automatic Virtual Environment) systems. Using the latter (see Figure 4), the interior space of a room has images projected on the walls, floor and ceiling such that it fully covers the user's field of view (Castronovo et al., 2013).

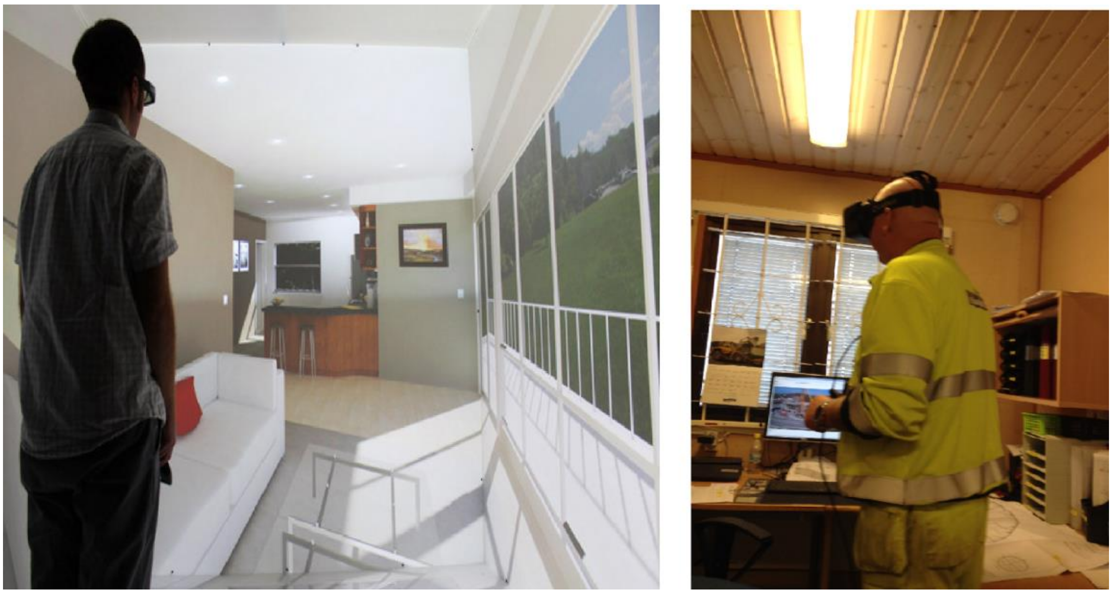

Figure 4 Immersive visualisation using a CAVE system (left) vs. a Head Mounted Display (Right)

It has been shown that immersive systems make an important difference in understanding the spatial information when compared with non-immersive visualizations. However, when comparing the semi and full immersion VR technologies, few differences were noticed during experimental design reviews sessions. The semi-immersive system was rated to be better suited for design reviews involving a larger group in conducting clash and coordination reviews due to its larger footprint. On the other hand, the fully immersive environment offered a better level of realism and ease of movement through the virtual model. Regardless of the technique used, both were considered helpful tools in identifying early design errors in the preconstruction phase (Castronovo et al., 2013). Other practical applications may consider the design of rooms with specific demands such as for hospital buildings. Such scenario is presented by Bassanino et al. (2010), where a wheelchair user tests the accessibilities of a room using a semi immersive environment. Based on the experience, this allowed a direct feedback to the design team to make the necessary modifications. The value of these immersive applications can allow a definitive validation of problems without requiring future meetings (Bassanino et al., 2010).

Compared to the traditional way of visualizing a BIM model using a monitor, by using an immersive environment such as a CAVE system, there were higher ratings in terms of ease of navigation, level of realism, sense of scale. Therefore this system can be more suitable for design and decision-making tasks but several constraints in terms of cost, accessibility and compatibility restricts its use (Johansson et al., 2014).

An alternative to the limitations of CAVE immersions, using a HMD can provide similar accessibilities without the mentioned constraints. Johansson et al. (2014) developed a BIM navigation interface using the Oculus Rift HMD, a Revit plug-in and a remote for navigation (see chapter 3.2.1). This system was evaluated in terms of rendering performance, navigation interface and the ability to support fast design iterations. The tested BIM model consisted of an architectural model of a real world project, a ten story building in Gothenburg, Sweden. The navigation interface has been shown to be easy to use even for inexperienced users e.g. construction workers. The interviewees, consisting of a site manager and construction workers, affirmed that the visual interface helped them to get a better understanding of the project as whole, as well as specific details. The possibilities of using the immersive navigation interface has been tested in the design phase, where fast iterations with complex geometry such as changing interior elements was done relatively fast e.g. 20 sec to 3 minute.

The presented system offers the benefits of fast design iterations, accessibility and low costs overcoming the barriers of traditional CAVE systems. It is therefore feasible to be practically implemented in design reviews of construction projects as well as to explore other possibilities in different construction phases (Johansson et al., 2014).

Cognition and spatial perception of visual information

The visual information can be understood by the human brain through mental images and spatial perception (Roupé, 2013). The visual cognitive process starts from the individual's experience of a visual environment, continuing with a two process involving a low level and a high level vision. The low level vision starts with the detection of simple details such as colours, edges which facilitates a higher level vision using object recognition, mental images general and manipulation. Further, this process accesses the long term memory of an individual by identifying and connecting to his or her past experiences. The object recognition connects to past mental images in order to make sense of the visual information.

This visual cognition information is then used for spatial reasoning, where the mind understands the space from a self-centred frame of reference called egocentric and an environment-centred called allocentric (Roupé, 2013). In the egocentric, the user compares him/her with respect to the object in the 3D space. In contrast, the allocentric uses a global system of reference by comparisons from object to object or object to environment in the visual environment. Moreover, the visual cues such as objects should be made recognizable in the virtual environment due to limited resources of the brain to construct mental imagery. This is important because more non-recognizable objects will require the creation of more mental images, limiting the brain resource to focus on the spatial reasoning.

In decodifying visual information, the field of view also plays an important role in spatial reasoning. According to Roupé (2013), the field of view and display system of non-immersive visualizations e.g. pc screens, need to be more detailed and photorealistic in order to provide similar spatial experience such as with large displays e.g. Panoramas. Furthermore, Castronovo et al. (2013) found that using designed facilities such as CAVE systems e.g. full immersive environment, provides a better spatial perception than large displays. This is because the human mind uses the body as a frame of reference to analyse the surrounding environment (Roupé, 2013). Moreover, the ability of own control over movement e.g. rotational movements using HMDs, and the use of joystick navigation intensifies the spatial perception in the virtual reality.

Distance estimation using different type of HMDs

As has been explained above, self-centred frame of reference called egocentric help the user´s mind to understand the space within the immersive virtual environment. Andrus et al. (2014) made a comparison between three different HMDs, where egocentric distance estimation was made. Twelve participants were part of this study where Nvis SX60, Nvis SX111, and Oculus Rift were compared with each other. The result shown how participants achieved the judged distance in the immersive virtual environment compared to the real distance. The true distance was from five meters up to ten meters. The result presented in *Ratio of judged distance to true distance* showed that the Oculus Rift had a ratio from 0.85 to 1.1, where the other two HMDs had ratios of approx. 0.47-0.61. With an almost double field-of-view (FOV), the Oculus Rift was explained to outperform the other two tested HMDs, regarding distance estimation.

According to Li et al. (2014) a large FOV may improve distance judgements in HMDs. Li et al. (2014) made experiments using the Oculus Rift HMD for distances from two to five meters. The technique was calibrated during experiments to a scale 1:1. The result showed that the scale 1:1 helped participants to judge targets with a 99.87% accuracy of the actual target distance. Within the same study, experiments using minified conditions (scale 0:7) increased the distance judgement. It was emphasised that more research is required. However, correct calibration as scale 1:1 is seen as important with regards to the comparison showed in Li et al. (2014). Specific type of HMD used for this thesis is explained in subchapter 3.2.1.

Figure 5 Nvis SX60 Young et al. (2014) (left) vs. Oculus Rift Development Kit 2 (Right)

3 Methodology

This chapter presents the specific methods used in this paper. First, the research approach presents the development of the paper, followed by an introduction to the case company and the case project. Second the collection of the empirical data together with its credibility and reliability considerations. Last, the identification of interviewees and description of the data analytic procedure used.

3.1 Research approach

To build the theoretical understanding of the topics and to develop the research questions an initial literature review was performed. The review include topics such the human and social aspects within construction projects and focuses on communication and decision-making, and focus on what is required to create mutual understandings. The literature concerns also the technical development of construction industry in later years regarding building information modelling and virtual reality.

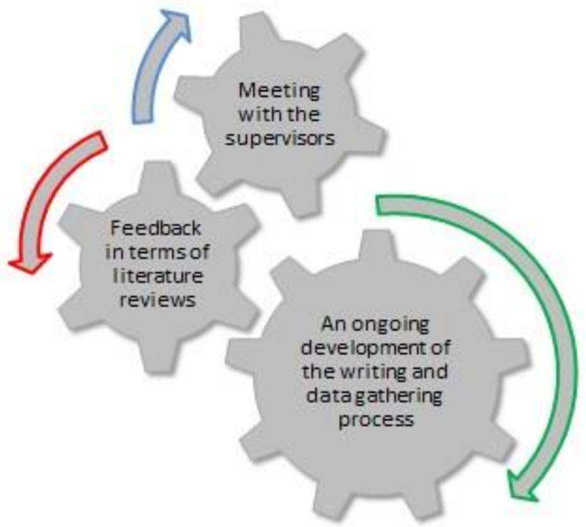

Figure 6 Process for quality development within the data gathering process

The literature review is based on scientific articles, books, web-site and other online publications. In order to identify the relevant data, Chalmers library and google scholar search engines were used, with keywords such as: communication in construction projects, decision-making, BIM and visualization, immersive reality.

Throughout this thesis, there was a continuous collaboration with the supervisor from the university and the supervisor from the company. Feedback in terms of the literature selection and guidance through the various stages of the paper has been on regular basis. The purpose for this collaboration (see Figure 5) was to support the quality development of the data gathering process and to improve the credibility-reliability of this thesis (see further below credibility measures, paragraph 3.1.2).

3.1.1 Case company - NCC

This thesis has been done in collaboration with NCC in Sweden, NCC Construction. The company is one of the main building and property development companies in the northern part of Europe (NCC, 2015a). The turnover for the year 2014 was 57 billion SEK and 18000 employees. In Sweden, the business is divided into four areas: NCC Construction, NCC Roads, NCC Property development and NCC Housing, where the Swedish market stands for 54 per cent of the net turnover.

According to the president and CEO, Peter Wågström, the company's vision and values need to be translated into real actions (NCC, 2015a). He stresses that the company should develop new products and be the first one who apply new methods and use innovations from NCC itself and from others. The department NCC Construction in Gothenburg became aware of BIM HMD by an involvement with the institution Chalmers University of Technology. After an introduction about this tool, held at NCC by researchers from Chalmers in December 2014, an interest developed of how this technique can be applied in construction projects, where one specific project was identified as suitable for its application.

3.1.2 Case project – SCA-huset

This paper is based on a case study consisting of a specific project, the SCA-huset (English: SCA-house). The architectural firm Rstudio responsible for the architectural design became involved through a competition, and since 2013 has been involved from initial design to a new detail plan in the specific area (Rstudio, 2015). The new building will have an office area of 25000 m^2 and will provide about 1000 workplaces. The building will also contain 180 parking lots. The project delivery method is design-build where the client is NCC Property Development (NCC, 2015b), see Table 1. The construction period started in 2014 and the building is schedule to be in use during 2016, see Table 2.

The SCA-house was considered to be appropriate as a case project for two reasons. First, the project provides the right conditions to examine the tool through all four project phases. Secondly, the tool has started to be applied even before data was collected, which fulfil the case project requirements.

Table 2 Main companies involved in the case project, (NCC, 2015b)

Role	Company/Department
User	SCA
Client	NCC Property Development
Main Contractor	NCC Construction
Property Owner (from year 2016)	Stena Property

Table 3 Project data, (NCC, 2015b)

Type of contract	Design-build, Partnering
Time plan (Feasibility- end of Construction)	Year 2013-2016
Area	25000m²
Environmental certification	Green Building, BREEAM (Excellent)
Selling Price	868 million SEK

3.2 Qualitative study

This paper is based on a qualitative study where semi-structured interviews were performed to collect the empirical data. This approach is adopted to establish the practical knowledge constructing the social reality in order to answer the research questions. According to Bryman (2012), a qualitative research focuses on the collection of empirical data quantifiable in words as opposed to numbers in quantitative approaches. The difference between the two methods does not rely only on numbers, as the former considers distinctive features such as inductive views, epistemological and ontological post. Qualitative research considers an inductive view as the theory is generated from the actual research while the latter two assume different views and properties of the social world and its participants. Moreover, a qualitative research is done in purpose to produce evidence based on the exploration of specific contexts and particular individuals (Brantlinger et al., 2005).

3.2.1 The HMD system

The interviewees tried the BIM HMD for approximately ten minutes before the questions were asked. This was done to provide the user with the immediate experience, allowing a better insight in answering the interview questions. In order to have possible the immersive BIM visualization, three different components were used: (1) The Oculus Rift HMD dk2, (2) the real time viewer application implemented as a plug-in in Revit Architecture and (3) a power point remote control (see Figure 6).

The Oculus Rift HMD is a new affordable (300- 350$) virtual reality device mainly addressed to the gaming industry. Its configuration provides approximately 100 degree field of view, stereoscopic 3D view including a gyroscope, as well as an accelerometer and magnetometer for user orientation in the real world. Moreover, the device allows a full screen resolution of 1280 x 840 pixels where the 3d scene is divided in two according to each eye, rendering effective resolution 640 x 800 pixels per eye (Johansson et. al., 2013).

Figure 7 Technical system required to navigate virtually

The rendering engine consists of a plug-in viewer integrated to Revit Architecture. This has been developed and is described in detail by Johansson et al. (2014). The steps to have the immersive visualizations requires loading the BIM model into Revit, then initializing the viewer from the add-ins tab. Afterwards, the user may connect the HMD to the computer to navigate through the model.

The configuration of the computer consists of an Intel i7 3.06 GHz CPU, 6GB of RAM and an Nvidia GeForce GTX 570 GPU, running on Windows 7 x64. The remote consists of a traditional presentation remote with four buttons for navigation.

During the interviews the BIM model of the case study project SCA house was used. Two different models were considered according to the background of the interviewee (see Figure 9 and 10).

Figure 8 SCA house - Architectural model

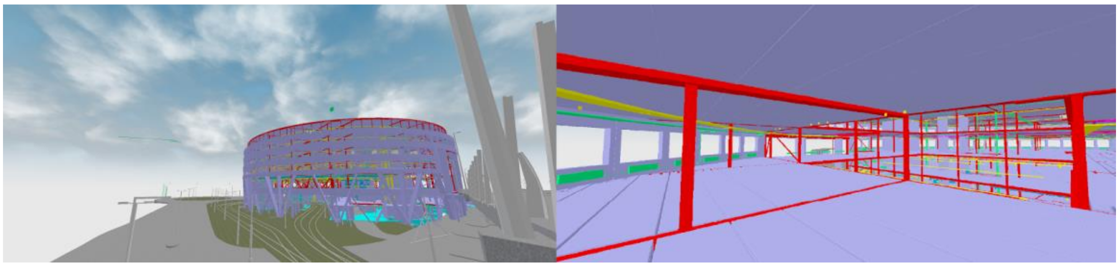

Figure 9 SCA-house - Colour coded model

3.2.2 Validity and reliability

Validity and reliability are important criteria in establishing and assessing the quality of a study. Reliability puts into question whether the results of a study can be repeatable under similar circumstances, whereas validity considers the consistency and integrity of its conclusions (Bryman, 2012). To evaluate this qualitative research, several criteria such as objectivity, trustworthiness and credibility have been be used.

To maintain objectivity as being neutral and distant during this type of research, personal positions, perspectives and value orientations have been clearly separated from the findings. This paper has followed 4 credibility measures for quality research, initially stated by Brantlinger et al. (2005). Hence, the theoretical framework has been developed by using *triangulation*, which comes from Triangulation Theory, where multiple perspectives (sources) are used to interpret a single set of data. Secondly, *research reflexivity* has been used, where the researchers have self-disclose their assumptions, beliefs, values, and biases. This specific measure has been considered both during creation of interview protocols and later on during interpretation of gathered data. Thirdly, *Collaborative work* is part of maintaining credibility with purpose to ensure that analyses and interpretations are based on more than one individual. Lastly, *External auditors* as peer reviewers and supervisor meetings (see Figure 6) have confirmed that the researchers' inferences are logical and grounded in findings.

3.2.3 Interview protocols

Interview protocols, consisting of the interview questions, have possessed a consistent approach but at the same time have allowed questions of flexibility. Reviewed theory from Hunter (2012), supported an increased awareness regarding the importance of using questions with an unbiased approach. However, this is presented as a difficult issue which every researcher must attempt to resolve. The questions in the protocols are therefore posed in a non-directive manner. This focus on non-directive questions aligns with the ambiguous to maintain flexibility. The importance of flexibility is also emphasised by Brantlinger et al. (2005). Based on this, the data collection is performed in a creative way where questions have been added and modified when more information emerged.

The interview protocols for this thesis were initially made according to a similar structure where all the questions were equally for each discipline. However, different level of understanding among the interviewees proved that similar structure not was suitable. Some questions proved to be unclear which resulted in small changes for mostly every new interview. Despite this level of flexibility the protocol structure was kept as before with the aim to possess an approach of consistency.

3.2.4 Group observations

The second method of collecting empirical data was through two group observations during the design reviews of the case project. Group observation, also called participant observation, can be simply viewed as taking part in a group setting to document certain processes and behaviours of a specific issue of interest (Bryman, 2012). The observations performed for this thesis were of a total of 4.5 hours of listening and observing behaviours. The observers were just being present and were not interacting or engaged in any conversations. Within the meaning of *observing*, Sanger (1996) stressed that the observer takes steps to counteract the in-built biases of people. This has been considered by the observers. Moreover, according to Sanger (1996), expectations before observations helps the observer to get started in setting up an analytical model. However, expectations may lead to blindness in face of the obvious.

Both occasions for observations were performed at the NCC Project Studio, where all the disciplines were gathered for an installation meeting with a total of fourteen participants. The other observation was performed at a meeting where clash-detection in the virtual model was performed. The purpose of observing both of these two meetings was to create a picture of how people communicate, looking at the decision-making process and to examine to which extent visualisations are involved in the meeting procedures. The observations also facilitated the identification of interviewees.

3.2.5 Group interviews

Group interviews were done with Strängbetong 2, Stena property and the local Fire department. The decision to undertake group interviews was based on the lack of knowledge regarding how these departments work in the construction and the operation phase. The decision is further based on the lack of insights of how these departments are involved in construction projects.

Techniques presented by Rabiee (2004) are used regarding focus-group interviews and certain framework for analysis. According to Rabiee (2004), most researchers recommend that participants should not know each other, to encourage more honest and spontaneous expression of views and a wider range of responses. However, the use of pre-existing groups such as acquaintances, could easily allow relating to each other´s comments, as trust within the group will encourage the expression of views. Referring back to the group participants, everyone within each group knew each other.

The project developer at Stena property involved the local landlord and the communicator with the reason that this new technology may also contribute to their working environment. The persons interviewed at the Fire department were selected by the station manager, where the newly employed fire inspector was present. The third person has over 20 years of experience with fire operations and is working now as a fire fighter educator in the Gothenburg region. Even that all interview participants were selected by the project developer and the station manager, the selection criteria stated by Rabiee (2004) has been fulfilled. These criteria are: participants have similar socio-characteristics, participants have something to contribute with, and that the selection is based on the participant's knowledge of the study area.

3.3 Identification of interviewees

The interviewees were identified by having the case study project as a starting point. To comply with the purpose of the thesis, interviewees from the different project phases, within and outside the company were selected. The selection started after the introduction presentation at the design meeting of the study project and continued during the group observations at NCC project studio. Project participants from different disciplines were asked to fill in an excel spreadsheet with their contact information and company. Based on their discipline relevance to the study, some of them were later contacted for an interview.

Certain interviewees who were not present during the group observations were difficult to identify. However, the supervisor for this thesis at NCC Construction recommended NCC Property Development as a suitable contact and part of the feasibility phase. Information from (NCC, 2015b) identified the main responsible for the project, the property developer. Furthermore, later during this interview with the property developer, contact information to the user SCA and to the future property owner Stena property was shared. These two companies were already identified during early group observations but without knowing the representatives.

Finally, including the fire department in the operation phase had its underlying purpose to explore if the future procedure will increase the demand of the BIM-model, even during building operations. A bigger demand through the whole project life cycle may initiate questions regarding who will own the model in the operations phase and who has the main responsible to keeping the model updated etc.

Project phase	Company, Department	Role	Job title	Years employed*
Feasibility	SCA	User	Facility Manager	1.5
	NCC Property Development	Client	Property Developer	(8)+2
Design	Rstudio	Architect	Architect, Administrator	0.5+5
	NCC Construction	VDC Coordinator	VDC Coordinator	(5)+2
	Strängbetong 1	Subcontractor	Structural Engineer	(7)+2
Construction	NCC Construction	Contractor	Site manager	(6)+15
	Strängbetong 2	Subcontractor	Assembling supervisor	
Operation	Stena Property	Property Owner	Project Developer, Local Landlord, Communicator	20, (10)+20, (7)+1
	Fire Department, Mölndal	Safety	Fire Inspector, Station Manager, Fire fighter Educator	N/A

* Early employment in construction projects + current, (number) Job title of a different character

3.4 Qualitative data analysis

Different approaches of how to analyse qualitative data have been reviewed even before interviews was performed. The underlying reason for this was to create an awareness of what is required within an analysis procedure and further create knowledge about the whole process to prevent any upcoming pitfalls. Procedures for data analysis and specific frameworks have been reviewed and compared with each other in purpose to generate the most suitable one.

Theory presented by St. Pierre & Jackson, (2014) has been of help regarding maintaining an analysis of quality. According to this research, presence is emphasised as a criteria for quality where data collected face-to-face is considered as of high quality. This criterion is fulfilled for all interviews performed for this thesis. Moreover, the development of the analysis has followed four steps stressed by Rabiee, F., (2004) as being systematic, sequential, verifiable and continuous. These steps will increase the extent of dependability, consistency and conformability.

3.4.1 Data analytic procedure

The data analytic procedure is based on two framework analysis, Krueger's framework analysis (Rabiee, 2004), and another based on certain steps presented by Creswell (2014). The second framework is used as a complement and it is suitable because of its similarities to the framework of Krueger's. Later research of Creswell (2014), recommends these types of frameworks as suitable for first-time researchers to manage the large amount and complex nature of qualitative data. Moreover, the framework enables data from both individual and group interviews to be analysed, which explain why this data analytic procedure has been used.

Krueger's framework consists of four steps as: Familiarisation, Identifying, Indexing and Charting. These steps are mirrored in the procedure shown in Figure 10 below, and these steps have been used as follows:

Organising and preparing data for analysis is done through the transcription of all performed and recorded interviews, in combination with field notes. These transcriptions were printed and compared with each other with the purpose to prepare for next analytical step.

Reading through all (familiarization) is done to understand the underlying meaning, where comments have been written in the margin, on separate papers not to be influences by others' notes.

Coding the data is the third step where similar topics have been clustered together. This was done by hand writing after reviewing transcriptions a second time. The developed list of topics was shortened to similar codes.

Following are *Themes* and *Descriptions*. The codes have been expressed in descriptive words where the codes were turned into categories. However, the interview protocol design, of questions already divided into themes, facilitated this step of the analytic procedure. The number of themes ended up below seven which is a general recommended.

Interrelating themes/Descriptions: Lines have been drawn between categories in purpose to show interrelationships.

The last step has been to *Interpret the Meaning of themes/descriptions*. The preliminary analysis has started to be developed. Even with a seemingly hierarchical approach, where the presented steps follows a linear structure, the data analytical procedure has been an interactive process where interrelated stages not always have followed the linear structure shown in Figure 10.

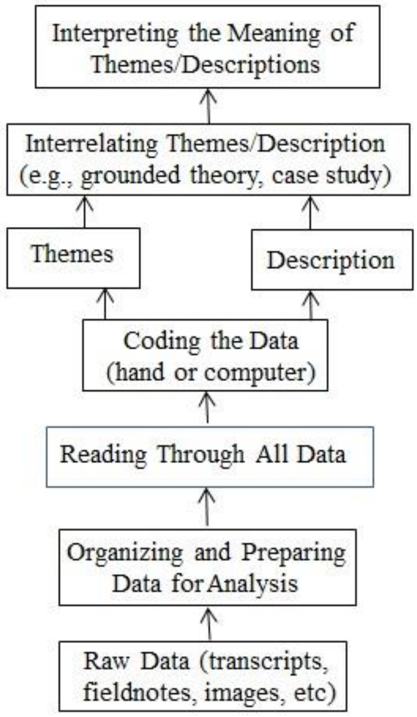

Figure 10 Data analytic framework, (Creswell, 2014)

4 Results

This chapter presents the results divided into three parts. First, communication using visualization points out how the interviewees communicate with the aid of visualizations within their organisation and in the case project. Second, findings regarding the BIM HMD are summarized, divided according to project phases. Last, knowledge from interviewees is presented regarding the application of new technologies from a general perspective.

4.1 Communication using visualizations

How project participants communicate using visualisations differs according the interviewed discipline. The findings are presented from the general observations during the design meetings and from project participants' own views regarding visualisation procedures. The following subchapters have the purpose to create a basic understanding of how the actual environment is in construction. This is to identify in which context and if there is a need for technology such as the BIM HMD.

4.1.1 NCC Project Studio - Design meetings

Two meetings were observed, first meeting regarding installations, and the second regarding collision detection. The observations took place in the beginning of March, to help identify future interviewees and define how participants collaborate in terms of making decisions.

The first meeting followed a list of question developed during the last meeting between the user and NCC Construction. The leader for this meeting was the installation manager. The projector was used to show which questions have been answered, according to each discipline. What was observed during the meeting was specifically the meeting discipline. Even when free/open discussions occurred involving both frustration and laugh, no one talk against each other. Also, each discipline discussed about their own area without getting involved in others.

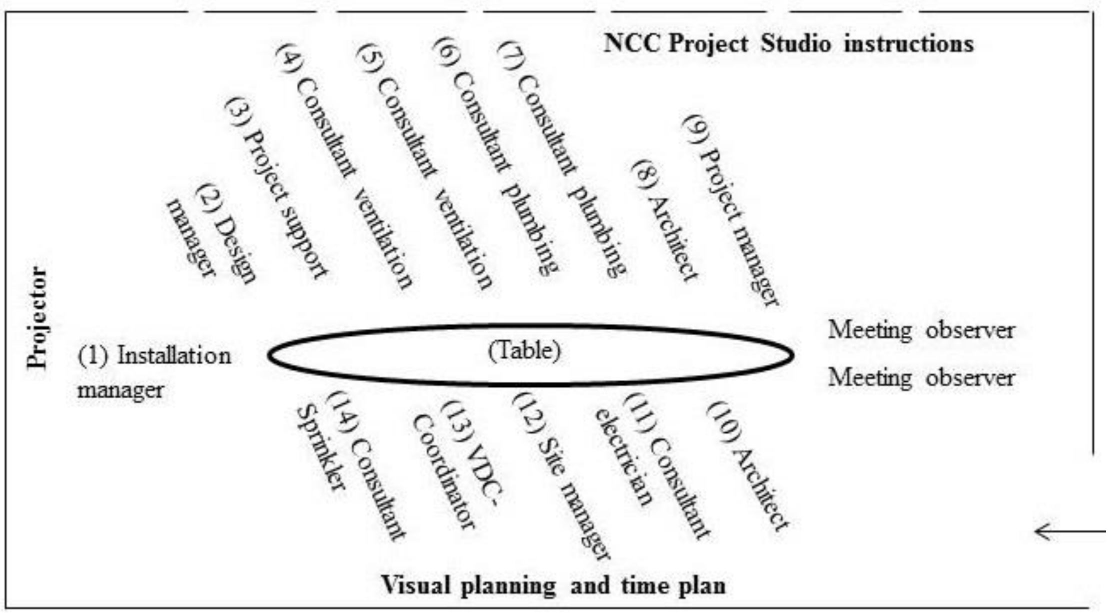

Figure 11 Observation during installation meeting, NCC Project Studio. Date: 03/05/15

Regarding visualisations, the projector was used. An interactive function of the projector was available but was not used due to issues with calibration. The architect was showing 3D and some 2D drawings to explain the reason for the upcoming questions. In addition to these specific drawings, drawings showing each floor of the building (posted on the wall in the meeting room) were used by the architect to connect easier to where the specific issue was located. New decisions made, and further developed questions were written on post-it notes and added to the visual planning board. A whiteboard was also used to highlight the next meeting. Finally, even with a clear meeting structure and a high level of respect among meeting participants, some communication barriers were observed. As an example, the architect communicated with the consultant representing the plumbing discipline. One was using hand gestures where the other pointed at a 2D drawing. Thoughts from the observers arise regarding how a virtual model would have been suitable to complement this discussion. Besides this, the installation manager explained difficulties to understand what the user wants and the user's questions regarding the design. Lastly, the consultant represented the plumber brought up issue regarding the 3D visualisations, where 2D drawings as .dwg-format are usually updated but where the 3D (IFC) models are not.

The second meeting considering collision detection, involving almost every person from the meeting described above. However, the installation manager, design manager, project manager were not part of this meeting. In addition to the VDC-coordinator employed for the project, a VDC-specialist led the meeting. The software Solibri viewer was used where a protocol (by the software) was used during the meeting. In comparison to the meeting described above, more concrete decisions were made during this design meeting. The reason why, was explained as *moving parts in the 3D model from one discipline to a new coordinate will affect another discipline. Therefore we need to be clear and decide upon what to do in detail and who has the final responsibility*. Moreover, the model was shown on the projector. Meeting participants asked the VDC-specialist to navigate to the desired place in the model. Some person even went in front of the meeting room, trying to look behind some pipes which were illustrated by the projector. The further chapters below describe each interviewee's own environment of using aid of visualisations.

4.1.2 SCA-facility manager

The facility manager is responsible for SCA's contracts in the northern part of Europe. In a typical project there is a steering group with top management. The interviewee communicates mostly with the steering group and internally with the representatives of the sub-teams and other project stakeholders. The first communication point is with the steering group and they transmit the information further. Involving people at lower levels would make the communication difficult because of the different levels of details discussed. For example it would be difficult for some people in the steering group to understand the movement of people or positioning of elements just from a 2D drawing. In this case, visualizations play an important role to let everyone understand. Pictures help with the communication, as the colours, textures etc. create the intended feeling. However, in the project teams flat drawings are enough and easier to work with.

Visualizations tools such as 3D models are not that common due to time considerations. For example in the SCA-house project, the details of some laboratory rooms started from a blank sheet, as an iterative discussion between architects and the lab-teams. Considering this project, communication with project participants is very important due to technical requirements of the building, such as room characteristics and equipment. Since SCA's knowledge area is not particularly in construction, it is difficult to detect possible architectural mistakes and know what is feasible. Here an active communication with guidance from the contractor is necessary. Otherwise the communication may also become redundant, discussing and answering the same questions. The facility manager stressed some issues regarding questions of same character which are brought up regularly, questions that according to the facility manager already are answered. Suggestions were made of changing how the contractor communicates with SCA. E.g. changing questions from *do you like it in this way* to instead asking *you said you like it like this - have a look here - it will be like this, is this what you want*? The facility manager saw a solution to these discussions of visualizing the design in another may, where a 3D model may be of use during these discussions. Finally, visualizations were described as to may help the decision-making process regarding problem-solving.

4.1.3 NCC Property Development – Project developer

As the project developer for the new SCA-house, the interviewee is the total economic responsible. This means that even the board of NCC has approved the project according to the financial requirements. The project developer has the responsibilities which involves the tenant SCA, and the investor Stena Property. The communication path will change during the feasibility phase. This means that a steering group has the main contact with the tenant and the investor. This occurs normally when the property development has found the future tenants and the project is sold to an investor. The steering group has the purpose to be involved during the design and decide upon more details that may affect the financial goals. These decisions are further transferred to the project owner on a regular basis via the steering group meetings.

Within property development the selling procedures are important steps in their work. Firstly, the property development needs to promote their ideas to their future tenants and find an appropriate way of communication and to reach a base of common understanding. Secondly is to sell the actual building to an investor. NCC property development is always promoting ideas that have not been built. 2D and 3D-drawings are used during these procedures. But with these drawings there are barriers for common understanding and instead pictures are used. In addition to pictures, reference projects work as a way of communicating ideas and show a real object of what the client can actually get.

The project developer emphasised the importance for the property development department to stand out and be in front due to the competitive market. Today, it is hard for the tenants to understand the ideas presented from the property developer. Even though, the pictures used are seen as the best way of visualizing their ideas. The pictures are more preferable compared to using a projector; this is with the reason that a projector does not create the right connection between the client and the seller. The interviewee described pictures as a natural way of meeting the client and discussing together.

The pictures are based on the software Google Sketch-up. The project owner described that there is willingness from the department NCC Construction regarding creating BIM-models initially in the feasibility phase. However, because architects prefer to work in Google Sketch-up prevent using BIM-models. Therefore, pictures are still seen as the most effective way of communication.

4.1.4 Rstudio – Architect

The interviewee works as an architect and communicates internally, with the user and with other project actors during design meetings. The visualizations are represented by sketches and drawings at an early phase, and also using just pen and paper. From that, as the project idea develops; 2D drawings are created and then transferred to 3D if it is required by the client or the project developer. To start directly in 3D would make the design process more complicated due to the many details of the model. But it is helpful to make the 3D model to get more insight of how the product may look.

Presenting visual material such as the above is very important in the communication with the client, colleagues and project actors, and it is an iterative process. The collaboration with the client can differ, sometimes they know what they want and other times it starts from a plain idea/image. In the second case, it is up to the architects to come up with ideas and many times a lot of work is done and then presented to the client to find out that "it is not what we had in our mind". In both situations, drawings and pictures are points of discussion. Also, during design meetings the communication is around drawings and pictures. When the ideas are presented without a visual aid, it is considerably much difficult for others to understand. The interviewee points out that is important to consider how much you show with the pictures depending on the stage, because the end product may look different, leading to different expectations, *if you get them a very good picture in the beginning, that will stick in their mind and they won't forget it!*

4.1.5 Strängbetong 1 - Structural engineer

The interviewee communicates internally with colleagues and with the project participants such as architects and contractors. The medium of communication is usually through weekly meetings, e-mails or by phone. The communication/visualization tools used are different BIM software such as Tekla Structures and for coordination Solibri Model viewer. From the first, details are extracted according to the requirements. IFC files are used as a common compatible document to collaborate and share files with other disciplines, together with 3D model visualizations which have taken the place of older 2D drawings. The details of how to work and communicate in a project may be described in a document employed by the contractor, in the case of the SCA-house this being the VDC project description.

The interviewee thinks that 3D visualizations are valuable because it can tbe projected and everyone can see. This supports communication during the meetings, providing a reference point for everyone. For example, in the SCA-house, some of the decisions are taken during the collision control meetings having the BIM model projected.

4.1.6 NCC Construction - VDC specialist

The interviewee works with 3D model coordination and clash detections during an early project stage and design reviews. Also, he has a technical support role for the use of VDC software and training/education in the construction phase. This involves communication with the different project stakeholders but also with craftsmen on site.

For visualizations, different software can be used such as Solibri and Navisworks. Using the projected 3D model is mainly used for visualizations in a project, but there could be also tools such as tablet pcs. At an early project stage communication using 3D modelling may be necessary to explain project specifics. For example, in the

SCA-house an initial meeting with the traffic authority Västraffik took place to explain how the construction can be built and how it will affect the traffic around the project site and safety.

A first point of communication is with the project manager who informs what kind of control check is going to be done during the next design meeting. During the meeting, the issue can be highlighted with less or more details depending on its complexity, and it becomes the responsibility of the design managers to go through the revisions. A usual design review session may take up to one hour and a half, time during which the interviewee and project participants must go through the whole model. Depending on the issue, decisions are taken having the 3D model as a support. Moreover, 3D model view-ports taken during the meeting with comments support the later modifications to be taken by the assigned discipline. During the design review meeting, the 3D model is the centre of the meeting.

The VDC project description is the contractor's internal document which informs the project participants how the works will be done and are the starting point for common understanding. The interviewee points out that the level of understanding between the contractor and the subcontractor is important, such that they all together work with 3D modelling both in design and in construction with assembling. Otherwise communication "clashes" may be possible.

4.1.7 NCC Construction - Site manager

The interviewee works as a site manager at the SCA project and communicates with a variety of stakeholders such as other managers, designers, architects, engineers etc. The site manager is the communication link between the design and production phase. Design meetings are used to discuss identified issues weekly. Other mediums of communication are phone as well as e-mails. Paper drawings are also normal in each project but site pictures are helpful to see the progress over time. Pictures from the 3D model are sometimes used for weekly planning.

Depending on the stage in the project, sketches are used to discuss ideas, then 2D drawings as a point of reference and documentation to what was decided and then using the model for when and how to execute. In the SCA project, the BIM model is essential for the design considering its complexity such as location, traffic, size and technical requirements.

The BIM model with the projector is very used because everyone can see and discuss around it. Other tools such as touch screen computers can be used. Tablets are not that practical since only one can see and it is not that portable on the construction site.

All project actors are informed through an internal information system where all updated documentation can be found, from drawings to the working environment. The level of details of the 3D model should be specific for the targeted viewer. For example for selling the building, specific colours should be used not to confuse the client. Communication and decision-making becomes harder when it involves costs and to understand something specific. For example, the feasibility of using a specific stair solution in the SCA house project required a long process to decide because of the costs and how it would fit.

4.1.8 Strängbetong 2 - Supervisor assembling

In addition to being main responsible for assemble the structure, the person is responsible also regarding the safety during this procedure. The person communicates through weekly meetings with the internal project manager and a frequent collaboration with the structural engineer (see 4.1.5 Strängbetong 1). The software TEKLA BIM Sight is available on site to visualize their daily work. However, due to a high level of work 2D-drawings were most preferable to use as the most effective way of communication. Another reason was based on what is most usable out in production, where 2D-drawings are more suitable than if everyone would use laptops. The interviewee described that there is actually one laptop/IPad on site but which has been broken during the last weeks.

4.1.9 Stena Property – Project developer, Local landlord, Communicator

As described by the project developer, Stena Property is not directly involved in the design regarding the development of the new SCA house. The involvement in the design phase consists of controlling the evolved 2D-drawings at NCC and the contact with their customer SCA. During the interview every participants were briefed about NCC using Building information modelling during the design, and were asked if this model has been shown. The answer from all three participants was no. In addition, the project developer stressed that it is always difficult to communicate.

Except from the new SCA house, Stena Property has experience from early projects where 3D-visualizations were used. The local landlord showed understanding regarding what is selling and what is not. For example, a lot of work has been put on colours and textures to increase the level of details, to understand how the actual building will look. However, according to the local landlord *pictures are not selling anymore*. Because of this, Stena Property is now part of different movie productions for selling spaces, for areas bigger than 1000 square meters. Using on screen visualisations with movies was described by the project developer to bring the advantage of having decided what the client will see. This creates possibilities to increase the level of realism in the movie with focus on specific details in the desired areas e.g. colours, additional objects.

4.1.10 Fire department, Mölndal - Fire inspector, Station manager, Fire-fighter educator

The fire department is highly involved when new buildings emerge. Today’s complex structures make it more difficult to adapt standard solutions considering fire protections calculated in theory. As an example, larger inside areas with walls of glass was explained as an issue. Complex buildings require major planning with regards to the operation phase, where this plan is translated into a so called *operation card*, which gives information regarding the positioning of objects such as e.g. gas or acids.

In addition to early involvement in planning future operations, the actual decisions of how to do fire rescue operations are transferred via 2D-drawings, where the operation card is one of them. All interviewees at the fire department explained the use of 2D-drawings as their way to get information from the property owner. Furthermore, 2D-drawings were explained to be used during (1) Fire inspections - preparedness before visiting the property. (2) Fire-fighter education - getting information on how the room looks like before entering it in total darkness. (3) Rescue operations - drawings placed at each entry at the properties. Some drawings are also electronically stored at the fire department's own database which is of use in the vehicle between the station to the actual fire.

3D-drawings or BIM-models are not part of their work. The 2D-drawings are only used and explained as necessary as the way of getting information. However, several issues were presented regarding this way of communicating. Firstly, drawings which are not updated was emphasised by all interviewees at the fire department as a tremendous issue. More specifically, the fire inspector explained that un-updated drawings give a false security regarding the building's fire safety. It was emphasised that even if the use of 2D-drawings would change to using BIM-models, the level of updated drawings/models would be equally important. Secondly, the use of 2D-drawings during fire-fighter education was explained by the fire fighter educator to not always be suitable. Information transmitted from the drawing is not always easy to interpret for everyone. What fire fighters have seen on the drawing is hard to remember when they later try to navigate in a room of total darkness. Thirdly, and final issue regarding using drawings to visualize the building, is during rescue operations. The station manager explained an issue considering guiding personal who are inside a building of fire. Today information is communicated as: *Walk approximately 5 meters forward and then you will find a second door on your right side*. Even when the personal outside will get a confirmation from the fire fighter, they will not know for sure which door is entered, where it could be the third door which leads to a different area. Hence, guiding their own personnel without knowing their positions inside the building affects personal safety.

4.2 Using the BIM HMD and benefits

The interviewees have shared their opinions regarding the possible use of the BIM HMD in the project phases. Areas of use are discussed in combination with specific advantages using the HMD system. Some suggestions need to be considered with future technical developments. Therefore benefits mentioned in the subchapters below need to connect with considerations presented in subchapter 4.3.

4.2.1 Feasibility

As a facility manager at SCA, the communication path is both with the contractor, but also internally with own employees. Parallel with the development of their new office, where the actual building starts to become assembled on site, questions have increased from the employees. These are out of curiosity of how the future building will look. Even a willingness internally to get more information on how the actual office will be, the facility manager has decided not to show the building information model too early. According to the facility manager, the employees have not been involved in all details with the reason that the steering group wants to be more ready. When reaching that stage, the BIM HMD was explained as a possibility to use. Considering this tool, *I think it is good to use the BIM HMD in communications, but at the same time as you are changing things, people may be upset if it is not the correct version*. Not using the tool too early in the feasibility phase is due to the level of realism. *The model is so real, using BIM HMD. The tool gives you a real impression, e.g. how the desks are positioned. This is why we need to be a bit wise to not use the tool too early. E.g. if I show the model to our employees with too much things in the model that are not similar to what the interior actual will be, I will get a lot of questions where people will wonder why they will not get a certain type of furniture, and further questions as if the furniture in the virtual model actual will be like what is shown*. Even these opinions, the facility manager saw the tool of use when it comes to decide where different furniture will be placed.

Moreover, the tool was explained to give a good first impression regarding the awareness of the new designed entrance. Even when navigating only for a short distance in the model, it was explained to contribute with a better understanding. In addition to what was mentioned early about the level of realism, the facility manager thought the architectural model (grey scale model) was enough because more details were not necessary. *Even that the model is very grey, I think I like this. When I looked into this grey model I draw my own conclusions of how the actual office will look like*. Moreover, experiencing the model at a scale 1:1 was explained as beneficial compared to 2D-drawings. More specifically, the tool makes it easier to see how many doors are needed to be opened before reaching a specific area. Also, it can be helpful to be aware how to find different locations or objects inside the building. For instance, finding the right suitable elevator, where the BIM HMD may help to simulate the reality to a higher extent. Finally, the facility manager considered that the tool can be part of the decision-making process. Using it early in this process, the amount of drawings showing many different solutions could be decreased.

Table 4 Benefits BIM HMD User

BENEFITS BIM HMD	User
Team collaboration	Trying different interior set-ups with equipment as part of the collaboration between the lab teams and the architects
Level of knowledge	Helps people with less knowledge reading drawings e.g. steering group
Feedback from employees	Inform employees and get opinions e.g. regarding heights, characteristics of furniture
Placement of new equipment	Seeing what equipment could fit in the laboratory rooms
Help identify walking paths	Understanding the flow of people going in and out of rooms
Better focus on details	The field of view is isolated which helps to focus on specific areas
Detection of design errors	Help to detect possible architectural errors by navigating in the model
Imagination and feeling	Fun to use, feeling how it is to walk inside the building, walk upstairs

From the perspective of a property developer, the communication point is mainly orientated towards the client, which may be a tenant or an investor. Many times the client may have limited understanding of how a future acquisition or rental may look, judging only from 2D drawings and even 3D representations; *it is really hard for normal people to read drawings*. *That is why detailed pictures are necessary, as it allows the client to visualize and imagine how it would be for someone to live there because it doesn't matter what you sell, the person really needs to love it first*, *and pictures say a lot*. With this purpose, attractive architectural models and realistic photographs with lights and shadows are created to reflect as much as possible the end product. Often, to create high quality photographs require to outsource services and the costs can amount to thousands of crowns per picture. The interviewee points out that the costs for promotion are very high, especially in bigger investments and there is always a risk of not getting the contract.

According to the interviewee, the meetings with clients are highly important and it might be a one-time opportunity in convincing to sign a contract. Here the BIM HMD can be very helpful. Using the tool for client visualizations can be a compliment to the pictures and drawings, and perhaps a more powerful experience. *I think this tool can help clients get in love with the project, and if they get to that step, it helps a lot*. This is because, first of the scale, it allows one to see how big or small an interior space is, which is difficult to appreciate from drawings or 3D models. Second the client can walk through the building and see how the colours and furniture fit.

Considering the tenant, it could be just a particular room or space. Some interior details e.g. furniture, are important to have as reference points regarding the size of the space to see how something is going to fit there. Considering a municipality client, visualizing with the BIM HMD can help to make sense of how a building looks in the context of the surroundings. In that situation, zooming in when one is outside the building will be necessary whereas in the building the scale 1:1 is more appropriate.

Table 5 Benefits BIM HMD Client

BENEFITS BIM HMD	**Client**
Using as a complement	Besides pictures, it could be an additional complement
Help clients to like with what they buy	Clients have difficulties to understand 2D and even 3D drawings. The tool could help in the selling procedure and may create the connection "seller-buyer".
New way of experiencing the building	Getting a feeling of how the rooms and interiors will be
Helps to understand volumes e.g. entrances	Better understanding regarding spaces inside the building, where this is difficult to be aware when reading drawings or viewing 3D models
Presentation of details	The level of details presented to the client are very important in communication, e.g. with spaces, furniture, room designs
Support client's decision- making process	BIM HMD may help to convince the client about the right location, type of house, walk inside and outside, which helps to remember the meeting
Urban planning	The tool may be of use within the process of urban planning

4.2.2 Design

During this phase, an iterative process of analysing how a project is undergoing and solving and answering questions that involve the different disciplines is done, usually in the context of weekly meetings. The architect, structural engineer and the VDC specialist are part of the design phase.

The architect considers that the BIM HMD visualization can be a good way to communicate and show designs to their clients but it is important to control what to show. This is not to promise too much and create wrong expectations. Considering a possible scenario, the tool could be used to decide upon issues in an early stage. It can also be a new approach to design a space and communicate with colleagues, to get the feeling of a room, heights and other details that simulate the actual reality. *It is a very good tool for us when we work, like just checking out how the rooms will look, and to try different ideas with our co-workers*. The visualization may also support the decision-making when considering a certain solution.

For example, considering the stairs solution in the SCA-house project, the tool would have been good to get a feeling of the heights and an overview of how it looks in the context of interior space. Moreover, the interviewee considers that the HMD visualization gives another level of perception considering the natural scale 1:1 combined with the level of realism. This can help to understand how big or small a room needs to be, how other objects in that room fit, because the display visualization does not give that feeling. In the discussion with the client it is better to have a higher level of realism, but with in-house design work, a high realism is not that important. That is because of existing knowledge but also a consideration to not get the model too loaded with information.

Table 6 Benefits BIM HMD Architect

BENEFITS BIM HMD	**Architect**
Sharing design ideas	Ideas could be visualized and further discussed with colleagues
Gives spatial awareness	Regarding room space, heights and volumes. New level of perception
Partly compatible	The tool is compatible with Google SketchUp using another viewer
Initial decision-making	Using the BIM HMD to figure out details such as how stairs could fit in the interior space of a building.

The structural engineer points out that it is indeed a new way of visualizing a building but for someone with experience in construction it is more or less the same as looking at a normal display. Moreover, the possibility of using the HMD during a design review meeting can be done to discuss complex issues or details *when you look at ten beams it is not clear that everyone talks about the same object*. According to the interviewee, the advantage of HMD is that one can turn off and on disciplines' details, making it easier to show what one is referring to. The level of realism and scale 1:1 can be of help in understanding how different construction elements could be assembled together, *the site manager can see the structure in scale 1:1 and then notice problems or solutions regarding how to produce or assemble.*

Table 7 Benefits BIM HMD Structural engineer

BENEFITS BIM HMD	**Structural engineer**
Colour-coded model	Different disciplines viewed in the model can be switched on and off when using the tool. It is a quick way to look below the surface
Interactivity	Interactive way of visualising the 3D model
Speed up decision-making	Using BIM HMD during design meetings can make the process quicker

The VDC-specialist shares opinions with the structural engineer. Both agree that the HMD is specific for people with less knowledge in reading construction drawings and with little use for people who work day by day with drawings and 3D models. According to the VDC specialist, the BIM HMD is of limited use during the design review meetings because project participants have already knowledge reading drawings and working with 3D models. Also, there is a need that everyone to see and discuss around the 3D model. A possibility of use might be in the situation of a specific issue which needs to be prepared beforehand because of the limited meeting time. For example, creating a section box for just a room, where one can see how the installation is designed and decide upon an issue.

The VDC specialist considers the use of BIM HMD more suitable for people with limited knowledge reading construction drawings. For instance, for clients in the collaboration with architects or/and during job planning for workers on the construction site. The assembly workers may use it as a complement to the 3D model, to see how the different elements fit together. For example, before the assembly of some elements e.g. columns, beams, each worker could use the HMD to go in the 3D model and see how it will be assembled. *Considering that category of people, the HMD visualizing is a powerful experience that helps to better understand the 3D model. To be in the model at a scale 1:1, it is a real world, a total new way to experience things, you can't misunderstand*. According to the interviewee, the HMD visualization limits the details to the immediate field of view and it is easier for the brain to process the information compared to display 3D model where every detail is present. *You are in the room so it is not that much information.*

Table 8 Benefits BIM HMD VDC-Specialist

BENEFITS BIM HMD	**VDC-Specialist**
Job planning	Can explain how works on site will be carried out and the assembly of elements
Using for pre-design	When pre-designing a room e.g. how to design ventilation channels, sprinklers etc.
Scale 1:1	The scale 1:1 leaves little room for misunderstandings. It is a different way to experience the building

4.2.3 Construction

The certain case project using NCC Project Studio influences how different disciplines are involved in the project, as the traditional boundaries decrease. Hence, opinions from the site manager regarding how BIM HMD is suitable in construction projects, consider both the design and the construction phase. Further, the supervisor for assembling has ideas to use the tool in assembling concrete structures.

The site manager was already introduced to this technique during a meeting in December last year. The meeting was held by the VDC-specialist, where the site manager was invited. The tool was applied into an actual decision-making process. The issue was regarding how the sun panels for each floor should be designed and assembled. The architect in collaboration with the site manager were not sure how the sun panels would be perceived by personnel sitting inside the office. The use of BIM HMD viewing the model at a scale 1:1 was explained to create a better understanding regarding this issue, while it shorten the time of the decision-making process. The site manager mentioned that *if we would have had the BIM HMD earlier, we could have saved several hours*. In addition to this, the tool has been used when deciding upon it is possible to stand upon the sun panels to clean the windows from outside. The site manager tested to wipe the window in the immersive environment, where it was examined if one person can fit on the sun panels, and perform the work at the same time. Decisions that involve large costs and where project participants need to have a wider understanding, was presented as difficult. In this regard the tool may be of help.

The site manager sees the tool useful within the design phase in helping to understand details. According to the interviewee, *this is just the beginning, in a couple of years the BIM HMD will be a useful accessory, where one may have them on site and just put them on to see something which is not clear*. The tool is further explained to be more suitable to be used by people without experience in construction. The client SCA was mentioned as suitable, using the tool when moving into the new office. Better understanding of the volumes and the interior in the virtual model may help the client to place the new furniture. Besides this, the tool was explained to give a more natural way of looking at things, compared to on screen visualisations. Thus, the details the site manager wanted to look at when using the tool, mirror what would be of interest to look at in the actual building. Moreover, the tool can complement the working environment; both in design phase as in construction, to easier understand how parts should be designed and then further understand how to actually assemble.

A colour coded model was used during the interview. The colours were seen as helpful to distinguish the different disciplines. Different disciplines were turned on and off when using the tool. Collision control was also used which made it faster to enter a specific room, three levels above. Finally, as was mentioned above, scale 1:1 facilitated the decision-making process regarding better understanding of space and volumes. However, as site manager with experience of working with 2D drawings, the tool is not really of a big help. *For a person with experience in construction, it does not really matter.*

Table 9 Benefits BIM HMD Site manager

BENEFITS BIM HMD	**Site manager**
Job planning	How to assemble and if the space is enough e.g. shading system, stairs
Decision-making	Planning interior space e.g. corridors, to get the confirmation who needs to assemble first and the sequence of work
Scale 1:1	A natural way of visualising the building, where the scale 1:1 gives the feeling closer to reality

Contrary to the site manager, the supervisor assembling had no early experience with the BIM HMD. Although, the same colour coded model was used where different disciplines were turned on and off. In addition to the supervisor for assembling, 8 of 16 people, working with assembling, were invited to test the tool and experienced for first time the immersive visualization. However, even trying to convince others in testing the tool, resistance was strong *I have already seen this type of technology, and therefore I am not interested to test it*. By explaining that persons may perceive the model differently using the BIM HMD compared to on-screen visualisations, more people started to test the tool.

When using the structural model in combination with only the ceiling turned on, the supervisor for assembling came with new insights. By using these two disciplines parallel, it was presented as an easier to understand where the joints in the concrete floor finally will be visible. Thus, using the tool to get this awareness before assembling the concrete floor sections was seen as an advantage. In addition to this, other personnel using the tool shared opinions regarding knowledge and learning. If the workers can see the model early in the project, the assemble experience may affect the structural design in a good way, where the thought is to change some details in the structure, based on what the workers find when looking into the model. However, on-screen visualisations may be just suitable for this knowledge transfer procedure.

Finally, several workers who tested the tool were interested regarding the steel structured. These people worked daily with welding parts together, and had the interest of navigating directly to specific places. A discussion started when the structural model was turned on with the steel model. When using the BIM HMD it was explained to create a deeper understanding on how the supporting beams during the assembly of the concrete structure (shown in the structural model) may affect the assembling of steel. Both workers and the supervisor for assembling stressed that the BIM HMD can be something natural to use each day before entering the construction site, based on that the model is updated and the tool is easy available.

Table 10 Benefits BIM HMD Supervisor assembling

BENEFITS BIM HMD	**Supervisor assembling**
Knowledge and learning	If using the HMD during the design phase, experience from early assembling can add knowledge and affect the design positively
Navigation	People had the interest to navigate directly to specific places where the person actually worked, without any instructions needed
View preliminary structure	Helps to understand how preliminary beams (used for supporting the structure during assembling) may affect the work.
Colour-coded model	With only the structural model + the ceiling turned on when using the tool, future visible joints between concrete elements were found. These joints will have different tolerances, which will be considered during the assemble planning and during assembling procedure

4.2.4 Operations

According to Stena Properties, the BIM HMD can be used to present different interiors of a building to clients, overcoming the difficulty of reading the construction drawings. Furniture from different suppliers could be tried and presented. The local landlord emphasized the level of realism, where it was stated that this needs to be very high. According to the Stena Properties interviewees, the experience of using the tool can create an open environment in the discussion with clients. *I got the feeling of the room and the possibilities of walking around, much more emotional than just looking at pictures or reading about it. The tenants can go and look for what they are interested in the building*. However, to return to what was said in subchapter 4.1.8 regarding the positivism's of using movies, the BIM HMD may, according to the project developer, give too many possibilities for the clients to navigate around and be aware of details in the model.

The local landlord saw the BIM HMD as giving the possibility of physically interacting with the model with a feeling of being "present" in the building. *I felt that I was controlling my walking and not someone else telling me how to experience the building*. All three interviewees stressed that the tool can be helpful in experiencing the heights and to be aware of the interior colours and textures. Considering these features, the interviewees saw the tool from a marketing perspective, suitable in the discussion for clients when renting, selling or developing a building or an area.

Table 11 Benefits BIM HMD Future property owner

BENEFITS BIM HMD	**Future property owner**
Better understandings	May help clients that have limited knowledge reading 2D drawings
Better selling environment	Fun experience when using the tool which creates selling/renting possibilities
Supports rental discussions	Good to use when discussing rentals with the customers
Level of realism	Creates the feeling of being present in the virtual environment.
Design iterations	Possibility to try different designs with colours and views for tenants
Urban planning	Municipalities may use the tool to understand how the buildings fit in a larger context
Citizens part of urban planning	It may help people living in an urban area to understand how certain areas will be developed in the future

Looking at opinions from the group interview at the fire department, the participants shared their own perspective according to their line of work. During the interview, the architectural model was viewed (grey scaled model). According to the interviewees the model was realistic enough. The interviewees stressed the willingness to just get the feeling of the room regarding distances. Moreover, the scale 1:1 was explained as important, especially regarding the spatial awareness. According to the fire inspector, the way of doing fire inspections may change in the future. The tool may give the opportunity to prepare the inspection in a virtual environment. To have an updated model for this procedure was explained to be very important. To continue, virtual fire inspections using the BIM HMD can help to get right the sense of the room, where the scale 1:1 helps to be aware if the fire equipment will reach the corridors inside. In addition to this, the tool may help to get a sense of the volume to understand how the smoke will be ventilated out from the building. Looking into a virtual model before visiting the actual building was seen as a great advantage compared to the first impression at site when lots of people are around. However, even if the tool may be used during future virtual inspections, details in the model regarding how doors will be opened for people evacuations need to be further developed (see subchapter 4.3).

A second perspective of how to use the BIM HMD came from the fire fighter educator. Instead of giving instructions using the 2D drawings, the tool may be more suitable. The procedure of training fire fighters is done using a room filled with smoke. A person will enter a total dark room and try to be aware how the room looks like. According to the fire fighter educator, the education would be better if the room can be shown virtually before entering it, to see the number of door and other details.

The third perspective is regarding the use of the tool during fire operations. From all participants, fire operations were emphasized as the number one reason why to start using the tool. Fire that occurs in apartments was presented as a minor issue, with the reason that each apartment usually has enough windows, which are of help during the fire operations. On the other hand, basements and bigger commercial buildings were presented as real issues. Sending in fire fighters in basements, sometimes 150 meters long without windows, was emphasized to put in danger the personnel's safety. Hence, the BIM HMD was discussed to prevent people to get lost inside the building. To be clear, the tool was said to not be used inside the building, instead the technology would be used from outside. *Using the tool for this purpose would be really great. From outside we can guide the personnel and e.g. say: no, you shall not go to the left to that specific door, you shall go straight forward*. In addition, the fire educator explained that fires in car parks are common, where several cars are located below the ground. *If the BIM HMD can help us during these procedures and decrease the operation with just 5 minutes, it would be appreciated*. By all interviewees, it was clearly said that the tool needs to be connected with an individual tracking system, knowing from outside where each fire-fighter is working. *This would be optimal, where we in that case can increase the safety. – The most important is that we know where the fire fighters are located in the building, and here the BIM HMD may be of value for us.* Further technology development, see subchapter 4.3.

Table 12 Benefits BIM HMD Fire department

BENEFITS BIM HMD	**Fire department**
Virtual fire inspections	By accessing the building virtually in a calmer environment, may help to initially understand the distance for evacuation in case of emergency. Updated models are of importance
Fire fighter education	Education in rescue operations regarding new complex buildings
Future rescue operations	If the BIM HMD can be connected with a tracking system, the tool can be a complement during rescue operation, where firefighters can be guided by the team from outside
Importance of scale 1:1	Important to be aware of volumes, which help to know distances considering if the fire hose reaches the corridor/room. Size of the room may help to understand how fast smoke will expand
Decision-making	Scale 1:1 help to take decisions regarding choose right equipment necessary to be prepared before operation

Benefits BIM HMD Summary

Project phases:	Feasibility		Design			Construction		Operation	
Organisation:	SCA	NCC PD	RStudio	Strängb. 1	NCC Con.	NCC Con.	Strängb. 2	Stena Property	Fire department
Disciplines:	Facility manager	Project owner	Architect	Structural engineer	VDC - Specialist	Site manager	Supervisor assembling	Project developer, Local landlord, Communicator	Fire inspection, Station Manager, Fire fighter educator
Area of use									
Marketing/Promoting		√	√					√	
Learning the building	√							√	
Design iterations	√	√	√	√	√	√		√	
Production planning						√	√		
Work preparedness						√	√		
Virtual fire inspections									√
Training of fire fighters									√
Rescue operations									√
BIM HMD use									
Positive to BIM HMD	√	√	√	√	√	√	√	√	√
Easy to navigate	√	√	√	√	√	√	√	√	√
Easy to connect			√		√		√		
Collision control on/off				√	√	√	√		

Abbreviations, organisations:

SCA	Svenska Cellulosa Aktiebolaget
NCC PD	NCC Property Development
Rstudio	Rstudio for Achitecture
Strängb.	Strängbetong
NCC Con.	NCC Construction
Fire department	Fire department, Mölndal

Abbreviations, disciplines:

VDC-Specialist	Virtual design and Construction-Specialist

Figure 12 Benefits BIM HMD Summary

4.3 Drawbacks and considerations

Drawbacks and considerations highlighted by interviewees are summarized in following table and described in more detail afterwards.

Table 13 Drawbacks/Considerations

Drawbacks/ Considerations	**Description**
Navigation	Relatively slow, time demanding. Requires the use of the mouse and keyboard. Inability to zoom in and out Difficult to find a specific thing without a shortcut
User category	Mainly addressed to people who have difficulties in reading construction drawings Specific uses by construction professionals
Dizziness	Possible for some users May depend on the level of details/time used
Tracking system	Inability to connect the BIM HMD to one's position
Compatibility	Not compatible with all BIM viewers e.g. Solibri, Tekla
One user experience	Only one user can visualize at a scale 1:1 The visualization cannot be extended to a projector
Accessibility	Requires: Computer, Head Mounted Display, navigation remote, BIM viewer and model.
Level of details/realism	Necessity to control the level of details showed at an early stage. More details are necessary in the visualization with the client.

Navigation

According to the VDC specialist, using the BIM HMD interface to navigate to a certain point in a complex model is a time demanding task and often difficult, considering the scale 1:1 and also the limited field of view. In this situation the collision control option needs to be deactivated to get to a certain location in the building or to use the mouse to get there. The structural engineer mentioned that shortcuts are necessary to get to a specific place; otherwise navigation with only the BIM HMD is slow. Most of the interviewees shared this opinion and mentioned that it would be good to navigate to different parts of the building and to access that fast. Another navigation constrained was using the BIM HMD remote to go back and forth in the model. Also, the facility manager considered the BIM HMD cable an inconvenient when navigating and turning around.

User category
Most of the interviewees considered that the tool is addressed to people who have limited knowledge reading construction drawings and working with 3D models. The VDC specialist mentions that one category is the construction workers on site, while the architect mentioned clients having difficulties in reading drawings as another category. Regarding the last, NCC Property development and Stena Property mentioned the same thing as drawings are very difficult to understand by clients. Also, the facility manager mentions that it is easier to understand with the BIM HMD visualization than looking at flat drawings by those who are not involved into all the details. A different opinion was expressed by the fire-department interviewees who mentioned that the BIM HMD visualization can be a complement to building inspections even if they have knowledge reading construction drawings.

Dizziness
One recurring aspect during the trial of the BIM HMD was the slight to moderate dizziness that some users had. For most of the interviewees this was just for a couple of seconds, while for others the dizziness persisted a couple of minutes after its use. The VDC specialist pointed out that this may depend on how much time one uses the tool and the level of details visualized. Other interviewees mentioned that the mind needs a couple of seconds to adapt to the virtual environment and to the details.

One user experience
A common drawback mentioned by the interviewees is the inability for others to see what the user sees during the navigation. The need to extend the visualization to a projector was described as a necessity in a group environment. In that context, it was suggested by some interviewees that real time design iterations would be a really useful feature to check.

Tracking system
According to the fire department interviewees, the tool needs to be connected to a tracking system, GPS or similar, regarding using the BIM HMD during rescue operations. As has been said in subchapter 4.2.4, the tool can be used both for virtual fire inspections and as for fire fighter training. However, to guide and know the location of the fire fighters inside the building during rescue operations, technological development focusing on a tracking system was described as being necessary.

Compatibility
Interviewees mentioned that some of BIM viewers such as Tekla BIM sight or Solibri model viewer is not compatible with the BIM HMD. This is an inconvenient such that files need to be converted according to the Revit software.

Accessibility
The technique used in this actual case project was briefly described in the theoretical framework (see subchapter 2.6.1). The accessibility of using the head mounted display requires a laptop with an advanced graphics card and a remote control, similar to what is used for a projector, to move forward and backwards, and to adjust the speed when navigating in the model.

Level of details/realism
Another common consideration was the level of details presented in the model. According to some interviewees, the BIM HMD visualization may need a high level of details and realism when working with clients. This may include different colours, furniture, avatars and shadows. Other interviewees mentioned that the level of details is not that important whereas the feeling of the indoor space and scale is mostly relevant.

4.3.1 Comparisons with on screen viewers

Interviewees agreed that the BIM HMD visualization can be a complement and it less likely to be a replacement to the traditional visualizations using 3D models or 2D drawings. In the table, some of the most common comparisons highlighted by interviewees are mentioned.

Table 14 BIM HMD in comparison with on screen viewers

Feature	**HMD visualization**	**On screen BIM Viewers**
Immersive environment	Full immersive	Non-immersive
Navigation	Slower	Faster/Relative to details
Scale	1:1	Variable
Level of realism	Higher	Relative
Field of view	Limited	Variable
Section creation	No	Yes
Ability to take measurements	No	Yes

4.3.2 Future developments

The findings of the interviews suggest eight suggestions of future developments to the BIM HMD visualization, considering its use in all project phases as:

- a higher level of details considering shadows and colours with client visualizations;
- wireless connection to the HMD to make the navigation more natural;
- visualizations only on parts of the buildings and shortcuts to access faster;
- extend visualization to a projector;
- possibility to connect a tracking system;
- possibility to take measurements and create sections;
- compatibility with other BIM viewers;
- ability to zoom in and out.

4.4 New technology implementation

The interviewees considered several factors as important when implementing a new technology. Some mentioned their opinion not only in the context of a project but also from a wider organisational perspective. Moreover, how the new technology is evaluated according to the interviewees is also presented.

Interest

Interest coming from employees or project participants is one of the most important considerations. Some interviewees expressed that it is important to take initiative and bring the information to the decision makers. For example, the architect brought the idea of having the BIM HMD internally, which resulted in buying it and experimenting with visualizations. Others have emphasized that the relationships in the organisation should be not on hierarchical level so it is easier to communicate and bring new ideas. The information transferred need to be directed to the responsible department otherwise something that can add value for the organisation can be missed. Also, from a customer's perspective, using a new technology to improve a service shows more care for the customer to deliver a good product. For example, using the BIM HMD to show the SCA-house at different stages was considered by the facility manager a good way to demonstrate the above.

Other ways of showing interest is to stay up-to-date with current research, references and seeing how the competition is doing on the market. Moreover, participating in conferences and having collaborations with education and research institutions gives access to new information. Not least, it is important to see the broader perspective and think outside the box, to be open to new developments even if the construction sector tends to be conservative.

Knowledge level

The contractor organisation should have the knowledge itself because external project participants are changing most of the times. The communication between IT/design departments with other departments should inform that a new technology is available for use and provide training and support. Moreover, project participants and employees should be comfortable with existing technologies whether it is a BIM program or a physical technology.

Responsibility

The project leaders should be saying what is going to be used in the project, acting as driving actors. If it is required to work with a new technology, for example a BIM software then it will be followed as a described requirement. The responsibility can come from a participant's side as well, to inform, but then manager is the one to decide. It may also depend on the contract's type, for example if it's a design-build contract, then the contractor has more control on what might be used. Costs need to be justified to consider the participant's proposal. Some interviewees considered that the contractor has the responsibility to decide what technology will be used in a specific project. From a broader organisational perspective, it may also be the situation when external consultants are employed to drive the new technology.

Trials

New technologies should be tried at a small scale while working with conventional methods. By trying something one can see how it applies in the organisation or in the project. If it proves to be beneficial then, one learns from the trials to improve it, as it is a time demanding process. If it is not, then it was just an idea proved wrong. *You need to dare starting using new things parallel to using your old technology*. Cost is of course a consideration especially at a project level, and one need to consider what percentage of the total project cost can be allocated towards the new technology. Last, it was pointed out that larger projects allow the trial of new technologies.

4.4.1 Measuring the value of a new technology

Even from interviewed disciplines not familiar with tools used in construction projects, perspectives were shared on how to measure value adding aspects of a new technology. Based on that, implementing a new technology requires sufficient time while fast evaluations do not give enough feedback. Therefore, the new technology needs to be tested in an early stage which creates the conditions of further evaluation.

Similar opinions were shared by the property developer but from a construction industry perspective. Knowing if the new technology will add any benefit was explained as difficult. However, low cost was seen as positive when initially choosing to adapt a new tool such as the BIM HMD. If the department responsible for new technologies (design department) will support property developers, the technology used will be improved constantly and further evaluated. Conversely, the VDC-specialist stresses the importance of having funding. Cases where the project manager is not convinced affect to which extent the technology becomes applied. Besides this, the level of knowledge among employees using it, affects how the new technology will be evaluated considering the right conditions.

In addition, measuring if the new technology is adding any value can be done by looking at other companies. Information shared from references, explaining how tools have been used and where benefits are presented is seen by the architect as valuable. However, decisions within the company itself needs to be taken where new tools may be tested during a one license or more, and then start to evaluate it. Using references as speaking with co-workers was stressed by other interviewees as a natural way of being aware of new tools. Using different forums and sharing information will initiate further judgement of how the technology can be used. In addition, the new technology may be evaluated according to financial measurements. The rate of return, somewhere around 5% was considered from the site manager as a reasonable requirement.

5 Discussion

This chapter aims to answer the paper's research questions. The results are analysed and compared with the theoretical framework with the purpose to identify similarities and differences with reviewed theories. The discussion will set the condition for the final conclusions.

This study has been delimited to only consider the construction sector. Also, the data gathered in order to answer the research questions has been limited to a one single case project. Since this study looks at the application of new technologies, less focus has been put on the implementation. Findings show opinions from each discipline interviewed regarding what is required within a project based organisation to implement new technologies. This study has not considered change theory and will not discuss what is required to implement a technology in a long-term perspective.

5.1 BIM HMD as a medium of communication

Initially in this paper the first research question was asked regarding; *how can the visualisation tool BIM Head mounted display be used as a medium of communication?* In order to answer this question it is necessary to start and relate the tool with the theory of communication. As was mentioned by Rayudu (2010), communication is a two-way process involving both transmission as well as reception. Even in the definition of communication, the number of persons involved in this process is described to be two or more. The theory presented regarding this subject is not exactly similar. As has been presented in Figure 1, the *David k. Berlo's Model* presents nine components, where the feedback is seen to create conditions to measure and evaluate the message received, which develops future communication. With this theoretical understanding it has been possible to define how the tool BIM HMD can work as a medium of communication.

Immersive environment of transmitted information

The result shows that the tool can work as a medium for transmission information from a virtual environment. This result means that a specific barrier for communication can be solved - faulty transmission. Early research identified this barrier as something that usually occurs when a message is sent via an appropriate medium or channel. Within the same barrier, presented by Dainty et al. (2006) receiving too much information leads also to faulty transmission. So, this technology shows upon a positive synergy effect, where it helps people to overcome traditional communication barrier as the immersive environment helps the user of the tool to focus on specific areas and prevent that too much information is received.

In comparison to on-screen visualisations the tool can transmit information effectively and therefore provides only information based on the user's own interest. But with an easier access to view details in the model comes requirements regarding the level of realism. Using the tool in future selling procedures will change an early controlled virtual environment as movies, to a higher freedom of movement for the customer. Now, the level of realism will be of importance in the whole model, where higher focus needs to put on certain colours, lights, surfaces and specific place of furniture.

As is stated above, the tool can work as a medium for transmission information. However, within the theoretical background, subchapter 2.6.1, this tool may help the process of communication even more. According to Roupé (2013), the HMD may even help to receive and decode information. This shows that technical development to an immersive environment help the communication process even more. Compared to Dainty et al. (2006), new ICT starts to be more applicable for several steps within communication. Though, even by Roupé (2013) it is still unclear if HMD can support people to perceive transmitted information, even within an egocentric environment.

Social aspects prevent technological application

Information from a virtual model will not consider the social aspects within the process of communication. This study confirms the first barrier, *A lack of clear objectives,* identified in early research by Dainty et al. (2006). Actually, the result in this study shows that the virtual model is limited used, even when the case project had requirements regarding using Building information modelling. The limited use of the virtual model within the case project is to not create wrong expectations. Thus, without clear intention when using the model and without explaining the reason of what the virtual model actually will show, the communication barrier defined in theory will still be present. Uncertainty of how the persons will perceive the virtual model will therefore even affect the technical application. 2D drawings will still be of use even when a virtual model has been developed and can be of help.

Needs of BIM HMD evaluation

Several possibilities have been presented in the result regarding how individuals experience the immersive virtual model. Better spatial awareness, colour coded models and possibility to walk the stairs are some of the benefits brought up. But even with several possibilities, it is a need to evaluate the BIM HMD. As an example, the tool does not reproduce the actual physical experience which will occur in the future building. Even when using scale 1:1 with a high level of realism similar to the reality, the tool will not provide the individual with physical indicators. For instance, the tool does not bring any physical experience such as: required effort when using the stairs, actual smells or actual sounds in the building. Taken these into considerations, a question arises, how lack of physical indicators may affect the memory? Cognitive and spatial perception is described by Roupé (2013), see subchapter 2.6.1, to help people who navigate with the HMD to actually remember the immersive environment.

However, there is still a need to evaluate how the BIM HMD may help people to remember what has been viewed. The time between viewing the virtual model to actually entering the finished building is long, especially for people within the feasibility and the operation phase. Within the selling process, using an immersive virtual environment it is not clear if sounds and certain smell need to be present at the same time. Further, within the operation phase it needs to be evaluated how the tool should be used during fire fighter education. A combination of using the tool and also visiting the property may affect how the staff will remember.

5.2 Possible applications in the project phases

What are the possible applications in the different project phases: feasibility, design, construction and operations? The purpose of this question was to identify the way an immersive visualization technology, the BIM HMD, can be used in the different phases of a construction project. Figure 13 summarized each of the application.

An increasing awareness towards BIM as a technology that improves processes and collaborations was found from the interviews. This confirms Azhar et al. (2012), that the sector is constantly advancing in this area. However, the results highlight that the BIM use is mainly emphasized around the design phase, with an on-going effort of integration in the production phase. Moreover, the knowledge of BIM in the operation phase is limited, as there are no future plans to use the BIM model. This is relevant as the application of the BIM HMD in all the project phases requires access and knowledge to use the BIM model.

Furthermore, the results indicate that the BIM HMD can be used in each of the project phases; however progressive trials and further developments need to be considered. According to the interviewees, the tool can be a complement to normal working procedures, being either used for a specific issue or on a regular basis. In addition, the level of knowledge of its users makes the visualization experience more specific for those categories who are not experienced with 3D models and drawings. It is to be mentioned that, considering the limited research and unclear way of using HMDs and VR in construction (Woksepp and Olofsson (2008), Roupé (2013), Johansson et al. (2014), it is challenging to give clear indications or makes comparisons. Hence, following on the interviewees perspective, together with literature on other immersive systems e.g. CAVE (Castronovo et al., 2013), possible applications are discussed below and represented in Figure 4.

Building walkthroughs and promotion of assets

During the feasibility phase, VR models are often used to try different building options and fast iterations (Bouchlaghem et al., 2005). Moreover, a close collaboration with the client is necessary to agree on a contract and discuss details. According to the property developer, the client meeting may be a one-time opportunity to decide a collaboration, and the BIM HMD is certainly of help. Its immersive visualization can be a complement during the meeting while discussing details and showing pictures. In this context, the identified uses are building walkthroughs and the selection of different interior configurations. According to most interviewees, *Building walkthroughs* allow the client to explore the building and specific rooms, having own control on movement and what one may want to see. Moreover, it can be a way to see which rooms are more appropriate for different equipment and furniture, according to the facility manager. Further confirmed by Craig et al. (2009), this application is a way to experience the building at a full scale, trying different accessibilities such as doors, using the stairs, lights etc. The selection and trial of different layouts, furniture and colours was also expressed as a desirable application by some interviewees. Direct design iterations with room modifications such as walls, windows, heights may be possible, however this may be not be appropriate at this stage because of the technical implications and knowledge area. Also, as highlighted by Johansson et al. (2014), this application needs to consider the time necessary to make the changes, the computer performance and may limit the level of details that can be changed at a time.

In addition, building walkthroughs can be used for the promotion of assets for renting, selling or developing a new facility. All interviewees involved in property development shared this opinion, showing also consensus in the difficulty of clients to understand 3D models or drawings. In addition, the level of details is very important when presenting rooms and buildings for marketing purposes. This is why photographs and videos help to create the right emotion, allowing one to put the visualization into own perspective, such as how it is to live there. In this regard, Weijermars (2012) mentions that emotions play an important role in the decision making of people. Therefore, the depth of details is relevant in creating the right emotion as it also enhances the immersive experience.

Urban planning

Another possible application is within *urban planning* according to some of the interviewees. This can allow seeing how the building fits in the context of the existing area such as other buildings and accessibilities. According to Roupé (2013) the association of VR with urban planning can support collaborations and decision-making, yet time and cost effective tools and methods need to be considered. In this regard, the results show that cost and time barriers are not an inconvenient for the tool itself; rather the focus should be aimed at the creation of the virtual reality models. Even at an early development with non-immersive e.g. on-screen, the use of VR models shows to have a great potential in property marketing (Bouchlaghem et al., 2005). Considering its accessibility and full immersive environment, the BIM HMD can assist property marketing, with a minimum of resources. Furthermore, as stated by the property developer, there are no organizational impediments that this could be tried with clients.

Design iterations

According to Johansson et al. (2014), the HMD system can be used during the design phase as way for design teams and clients to experience immersive visualizations without the need to travel to a specific location. Therefore it can be a portable system to communicate the design to the client. However some interviewees point out that the immersive VR models needs to be prepared in advance, controlling the details presented. Regarding discipline design meetings, the VDC specialist thinks that it may be used but a specific issue needs to be addressed. Such an issue is exemplified by the site manager, where the tool helped to better understand the right positioning of sun panels. Other examples given by interviewees consider analysing the suitability of staircase solutions, placement of specific equipment and installations in a specific section. The architect points out that trial and evaluation will permit one to say how helpful the tool is to solving a specific situation. This points out that even with specific issues, using the BIM HMD may be or not a problem solver. However, research following this context e.g. Bassanino et al. (2010), shows that the immersive environment can reduce the number of design meetings as changes can be made directly with faster consensus. This is especially relevant when the design team needs to closely work with the client to understand specific requirements such as the design of unconventional rooms to suite particular equipment and installations. Last, as mentioned, direct design iterations in the immersive environment with the current BIM HMD system needs to consider future developments (Johansson et al., 2014).

Job planning

The BIM HMD could be used in the construction phase for *job planning* according to the findings. In this phase, Woksepp and Olofsson (2008) considers that VR models helps to better understand the overall building process. All interviewees with experience in the construction phase saw the BIM HMD as a helpful accessory. An example was its use for construction workers before the assembly of elements such as concrete sections. According to Castronovo et al. (2013), the 1:1 scale of the immersive virtual reality can eliminate the need for one to imagine the space and movement of objects from scaled drawings or models. Therefore, construction workers may visualize how parts should be assembled during their day of work even before starting it at a natural scale. This may also overcome the problems of faulty transmission of information highly frequent in construction (Dainty et al., 2006). Also it may be address the limited knowledge of reading drawings or 3D models of workers, according to some interviewees.

Moreover, the assembling supervisor considers that if workers use the tool early in the project, the assembly may be affected in a good way. Also, it may lead to ideas how to solve certain details based on the navigation at a specific section. Also, the site group interviewees showed that the BIM HMD was quite easy to use even for those without experience with 3D models, which confirms similar findings to Johansson et al. (2014). The supervisor assembling considered possible a day by day use of the tool before entering the site; however this requires an updated model and the accessibility of the tool. Connecting to the last, as the use of BIM HMD is envisioned possible in this phase; the authors consider that this may also drive a more frequent use of 3D models, as a requirement to use the tool.

Fire safety operations

Interviewees involved in the operation phase, had different opinions on how the tool can be used as they represent different disciplines. A common finding show that neither of the interviewees in this phase have access or work with the 3D model of the case project. This may be explained by the current construction stage of the case project but at the same it may indicate that the value of using a BIM model in an operation phase is not seen advantageous. Another common aspect mentioned by these interviewees was that it is very important to have updated drawings. This can be highly important in the case of the fire department when performing fire operations to find the right paths and doors. In addition, this is relevant when considering the lifespan of buildings and their changes in function and owners over time. Considering the application of the tool, the immersion experience was positively perceived the fire department group, bringing new perspectives of applications. By performing different fire safety operations e.g. virtual building fire inspections, a faster process of learning the building while experiencing its heights and volumes can be a good preparation before the actual physical inspection. However to have this applications possible as other mentioned in the result, the BIM model must be made accessible by the client. Further, knowledge to use the model and updates need to be considered.

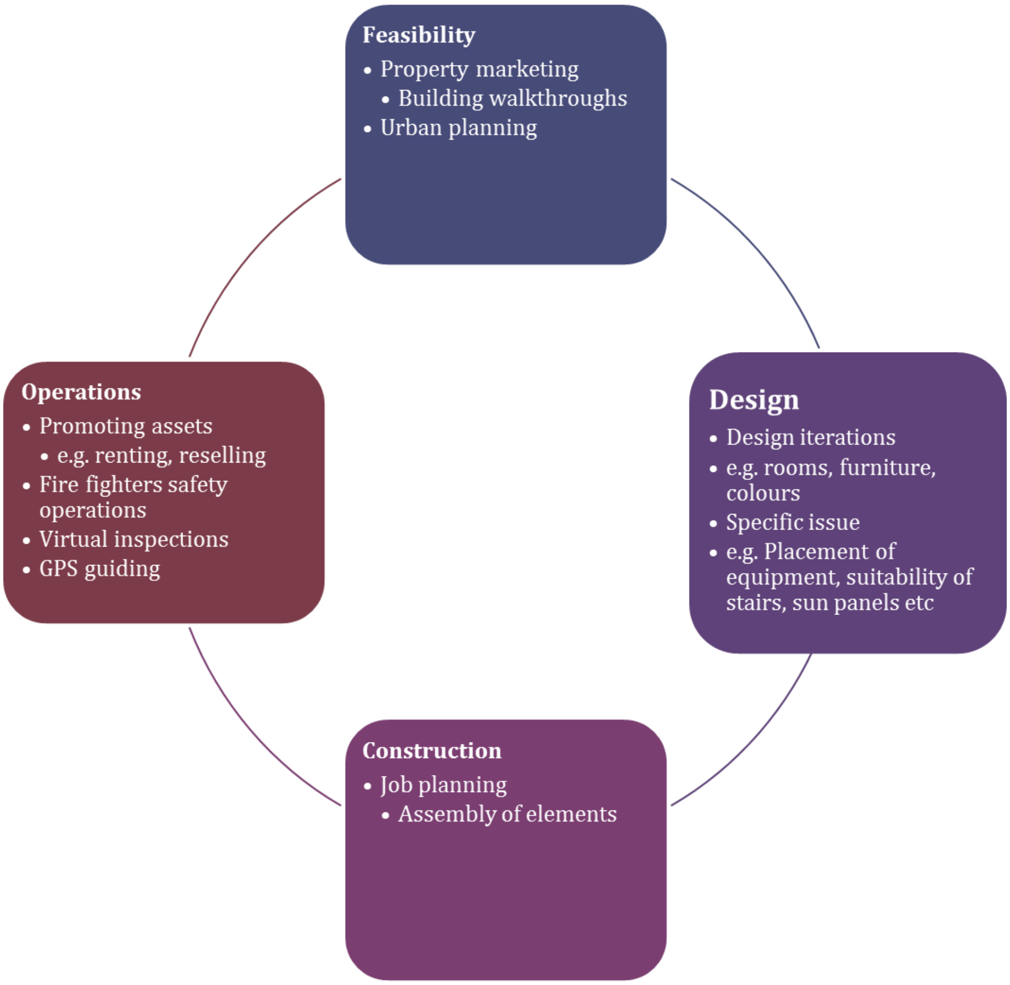

Figure 13 Identified applications of the BIM HMD according to the project phases

5.3 Benefits and drawbacks

The third research question was: *Does the use of BIM HMD brings any benefits, has drawbacks?* The findings indicate that the BIM HMD visualization may be beneficial mainly due to the spatial reasoning and sense of scale given to its users. By visualizing recognizable objects e.g. building elements, at a natural scale the human mind finds it is easier to recreate mental images to make sense of the visual information Roupé (2013). This helps the decision-making process and may overcome the person's individual interpretations. It also explains why certain categories of users e.g. not industry specific, may understand easier in the virtual environment, while for other categories e.g. professionals, it does not make much of a difference. Even for the later, analysing a problematic issue from a new perspective can lead to new ideas and confirms already tested solutions. Not only that those decisions are reached easier when the user understands the transmitted information, it also facilitates a faster consensus and agreement. This may either save time in design reviews, help clients to understand his possible acquisition or facilitate a better assembly on the construction site.

Considering the technological accessibility, the system presented in subchapter 3.2.1, has the benefit of portability, accessible cost, compatibility with commonly used software e.g. Revit Architecture, ease of use and connectivity.

The images per second rendered by the HMDs facilitate a real-time performance with complex VR models e.g. building + surroundings Johansson et al. (2014). The main features of immersive visualizations such as level of realism, scale and field of view were confirmed by interviewees as mentioned by Castronovo et al. (2013), using immersive facilities. A new feature identified is the feeling of control on own movement. In contrast, the ease of navigation was not perceived as an advantage. Considering the similarities of features it is put into question if the HMDs for immersive visualization can replace expensive systems such as CAVE or Panoramas.

Among the drawbacks of immersive visualizations is the limited numbers of users that can participate during the immersive visualization (Roupé, 2013). The BIM HMD allows only one user to be immersed in the virtual reality. This is considered to be a drawback in situations where others need to see and collaborate. In the situation where the BIM HMD visualization may be extended to a secondary screen, its viewers may not take advantage of the immersive features. Considering the actual use, some interviewees pointed out the need to get to a specific place much faster.

Slower frame per second e.g. 15 when visualizing virtual models may lead to the so called 'motion dizziness' (Roupé, 2013). Despite a higher fps using the BIM HMD, some users also experienced short to moderate dizziness. However, this was not common for interviewees, some described just a couple of seconds necessary to adapt to the visual environment. Last, the use of the BIM HMD system requires compatible software as presented in subchapter 3.2.1. Therefore, the file format must be similar or converted to the compatible software.

5.4 New technology within a project based organisation

In addition to examining possible application of the tool, the last research question within this study had the purpose to look within an organisation. The question, *what is required within a project based organisation to implement new technologies*, is answered by looking at how the actual tool has started to be applied and compared with the theoretical framework. To be noticed that, the case project will be compared with the theoretical framework considering implementation, even if the tool BIM HMD only has been applied.

The theoretical framework describes the conditions within the construction industry where the project based organisation structure is mostly common. As has been mentioned, construction stands for 8 per cent of the gross domestic product (countries within European Union) where projects are central to the economy. With regards to this, it is clear that the industry need to take responsibility and implement new technology in order to be more efficient. Bower (2010) explain construction sector as has been facing high level of turbulence according to rapid advances and complexity in technology. Though, within this turbulence positive outcomes occur where traditional barriers between industries decrease.

The result confirms this early research where the actual case project has shown a high level of involvement between different industries, namely the manufacturing industry (building structure) in close collaboration with the main contractor. For instance, the case project using *Partnering*, see table 3, with specific requirements regarding the use of BIM, involved subcontractors already in the design phase. Moreover, the use of

BIM technology has been of importance to solve complexities within the design phase regarding problems usually occurring in the construction phase. Notable, Froese (2010) presents the construction industry as being of fragmented nature. Though, this specific case project shows upon a different environment which has affected the technology implementation process positively.

Process for technology implementation

The process required for implementation within an organisation is presented in the theoretical framework (see Figure 2). The result in this study shows upon several similarities of how the BIM HMD actually is applied according to what is recommended in the theoretical framework. For instance, this certain technology has started to be applied from a lower level with purpose to identify the need. The result shows that the VDC-specialist has taken this responsibility. In this case project, the low levels of management have carried out first trials at a smaller scale. Within this process of implementation, next step considers potential solutions which are summarized as benefits and drawbacks. Hence, this specific master thesis stands for this step within the process. This study will be later presented for middle levels of management which may result into a proposal to be assessed by the senior management. However, even with a clear process for technology implementation the specific case project shows upon several barriers.

Identified barriers for technology implementation

Fifteen barriers are presented within the theoretical framework, see Figure 3. Some of these have been identified in the actual case project at a project level. Firstly, *tight project timeframe* contributed with high level of stress among several project participants, which affected to which extent the tool was introduced and initially used. The barrier *lack of IT leadership on projects* was overcome by high involvement by the VDC-specialist in collaboration with the VDC-coordinator. However, even this leadership took several weeks before the technology entered the project site. The reason behind this may be the high level of stress because of the project timeframe. In addition, the barrier *Fear of change and uncertainty* was identified within the construction phase. The site manager describes the construction sector as being conservative. The group interview, gathered several people working on site with assembling, confirms the site manager's view regarding the sector's conservative nature (See subchapter 4.2). Conversely, the majority of the interviewees did not show any fear of change. The result shows openness to new technology and awareness among project participants, that it is necessary for employees within an organisation to stay in front and not to wait to apply new technologies.

Besides the barrier at a project level, Figure 3 presents barriers at an organisational level. The project manager, who is the main responsible, regarding the design-build contract, considers the barrier *reluctance of management investing in innovation*. The VDC-specialist stresses that some initial investing need to be done in the specific case project. Even with a lack of knowledge if a new technology will benefit the organisation, funding is explained as necessary. If this barrier would be overcome, the responsibility for its implementation will be clearer, where the project manager may create guidelines regarding application and further implementation for certain techniques. From the interview question; *what is your responsibility for this application*, the answers were very unclear among projects participants (see Appendix), this emphasizing the importance of considering this barrier.

6 Conclusions

The purpose of this thesis was to examine how the BIM Head mounted display can be applied in a construction project, by looking into all the phases; feasibility, design, construction and operation. The result shows that the tool can have applications in the above phases, mostly as a complement to working routines or either for specific situations. The features of the immersive visualization can be helpful for those categories of people with less knowledge in reading drawings or working with 3D models. In those categories, clients and construction workers are mainly of focus. The spatial awareness gives a new perspective to view the BIM model, which can help professionals to analyse proposed solutions and decide faster. This is highly relevant for specific building requirements, where the knowledge between the design team and client organisation may be inconsistent. Moreover, BIM maturity needs to extend to the operation phase to consider some applications. Consequently, using immersive virtual reality was perceived with positivism however there is not a clear way of how it can be used to provide tangible benefits.

As previously stated, the implementation of a new technology should follow a required process, started by lower level management, followed by a proposal to be assessed by senior management. As has been noted, the actual case project in this thesis has followed this required process for technology implementation. Although, this study points out that there is a missing link between lower management and senior management. The goals and vision stated by the CEO need to be further translated into each construction project, to better understand why certain technologies should be applied. Also, who is responsible for this process needs to be clearly indicated. The suggestions presented in the discussion have been developed in order to support the future process for implementation and to provide what may be of interest for all project participants.

Suggestions to the case company

Several driving factors for implementation are presented in subchapter 4.4. The level of *Interest* is described as the most important consideration. During the interviews several questions occurred as; compatibility with other technologies, required knowledge before use, as questions regarding how much time is needed to wait for further technology development. These questions show an actual interest for the BIM HMD and other new technologies. However, a high level of interest among project participants does not answer questions of *how* to implement new technologies.

Below, suggestions are presented to what may be of interest for the case company involved in construction projects. The suggestions are the outcome from what has been identified as necessary after the result has been discussed. The suggestions are given to specific disciplines and divided into project phases.

If a technology similar to what has been studied in this thesis will be used in the future processes at the department of Property development, several aspects are important to be considered.

- Define the interest of using viewers similar to what has been studied. If interest:
- Establish guidelines on how building information modelling should be applied.
- Inquire architects that are knowledgeable working with BIM in an early phase
- Decide upon how to share and how to keep knowledge with the technical department.

Within the design phase, where requirements regarding the use of BIM already exist other suggestions are suitable. These especially refer to what is needed to use the models to a larger extent.

- Create clear objectives regarding (1) why the model is used, (2) what the model is representing, and finally (3) clarity on what is possible to decide upon. This is in order to overcome one of the communication barriers and therefore prevent wrong expectations.
- Involve the project manager if possible and decide how certain technique will be used. Specific investment requirements should be added to the project budget.
- Continue to collaborate with universities and stay updated regarding technology development. See future developments subchapter 4.3.2.

With regards to this case project, the contract design-build provides good collaboration between the design phase and the construction phase. Therefore, suggestions presented to disciplines within the design phase are applicable within the construction. Further suggestions are:

- Decide upon how project participants will be informed and educated regarding the use of new technology.
- Evaluate new technology on site by gathering valuable feedback from project participants.
- Create consistency regarding the update of BIM-models each week. This has been presented as an issue on site where it is unclear if the model is updated or not.

Within the theoretical framework, technology as BIM is commonly used through the whole life cycle of a facility. The result shows that BIM models are not used within the operation phase, this even when these type of models are required in the certain case project. Though, a high level of interest is shown both from the future property owner as from the fire department. As has been mentioned in the result, both parties within the operation phase have shown openness to new technologies and explained their implementation as necessary in today's environment. Further suggestions are pointed both in a short and a long term perspective.

- Future property owner needs to be more knowledgeable regarding the technique that is available within the construction project.

- Need to identify if there is a reason to actually own the BIM-model as part of the facility management. The fact that the property owner in the case project only will buy the 2D-drawings creates a gap between the construction phase and the operation phase, regarding the use of this technology.
- Considering the fire department there are several possibilities of using new technology to increase the safety operations within the society, where the suggestions are meant in a longer perspective. Firstly, the need of further developments, see subchapter 4.3.2, requires collaboration with technical universities or IT-companies in order to find a long term technical system.
- The fire department needs to look upon their strategy with regards to new technologies. A new strategy should also include the municipalities with the reason that this will affect the society to a larger extent. These suggestions came from the fire department itself and were emphasised as possible, even being aware of its complexities.

Further research

Considering the HMD technology at its beginning stage in construction, the possibilities of research are many (Johansson et al., 2014). An in-depth analysis of each of the applications identified in this studied after a natural use of the BIM HMD may give clear uses. In particular, client visualizations during design reviews are perceived as an area of great interest (Bassanino et al., 2010).

The results show that the HMD immersive environment presents similar features as special designed facilities such as CAVE systems. Therefore, further studies are needed to compare the two systems in different contexts, as well as if the current HMD technology can replace expensive CAVE systems. Technical improvements as highlighted in subchapter 4.3.2 were pointed out as desirable by interviewees; therefore a focus on each may stand as further research to improve the immersive experience.

References

ANDRUS, S., GAYLOR, G. & BODENHEIMER, B. Distance estimation in virtual environments using different HMDs. 2014 2014. ACM, 130-130.

ANTHONY, R. N., HAWKINS, D. F. & MERCHANT, K. A. 2011. *Accounting: text and cases,* New York, McGraw-Hill/Irwin.

AZHAR, S., KHALFAN, M. & MAQSOOD, T. 2012. Building Information Modeling (BIM): Now and beyond. *Australasian Journal of Construction Economics and Building, The,* 12**,** 15-28.

BASSANINO, M., WU, K.-C., YAO, J., KHOSROWSHAHI, F., FERNANDO, T. & SKJÆRBÆK, J. 2010. The Impact of Immersive Virtual Reality on Visualisation for a Design Review in Construction. 585-589.

BOUCHLAGHEM, D., SHANG, H., WHYTE, J. & GANAH, A. 2005. Visualisation in architecture, engineering and construction (AEC). *Automation in Construction,* 14**,** 287-295.

BIM Guidelines. 2012. http://www.nyc.gov/html/ddc/downloads/pdf/DDC_BIM_Guidelines.pdf. [Accessed 2015-02-25].

BOWER, D. 2010. *Management of procurement,* London, Thomas Telford.

BRANTLINGER, E., JIMENEZ, R., KLINGNER, J., PUGACH, M. & RICHARDSON, V. 2005. Qualitative Studies in Special Education. *Exceptional children,* 71**,** 195-207.

BRYMAN, A. 2012. *Social research methods,* Oxford, Oxford University Press.

CASTRONOVO, F., NIKOLIC, D., LIU, Y. & MESSNER, J. An evaluation of immersive virtual reality systems for design reviews. 13th International Conference on Construction Applications of Virtual Reality, London, UK, 2013.

CRAIG, A. B., SHERMAN, W. R., WILL, J. D. & SCIENCEDIRECT 2009. *Developing virtual reality applications: foundations of effective design,* Oxford; Burlington, MA, Morgan Kaufmann.

CRESWELL, J. W. 2014. *Research design: qualitative, quantitative, and mixed methods approaches,* Thousand Oaks, SAGE Publications.

DAINTY, A., MURRAY, M. & MOORE, D. 2006. *Communication in construction: theory and practice,* London, Taylor & Francis.

DOLINSKY, M., MCDOWALL, I. E., SCHULZE, J. P., HUGHES, C. E., ZHANG, L., EDELSTEIN, E. & MACAGNO, E. 2014. CaveCAD: a tool for architectural design in immersive virtual environments. 9012**,** 901208.

EASTMAN, C. M. 2011. *BIM Handbook A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors,* John Wiley & Sons Inc.

FROESE, T. M. 2010. The impact of emerging information technology on project management for construction. *Automation in Construction,* 19**,** 531-538.

GOMEZ, K. 2006. Improve communication in the construction industry. *Construction Contractor***,** 44.

HENDERSON, J. R. & RUIKAR, K. 2010. Technology implementation strategies for construction organisations. *Engineering, Construction and Architectural Management,* 17**,** 309-327.

HUNTER, M. G. 2012. Creating Qualitative Interview Protocols. *International Journal of Sociotechnology and Knowledge Development (IJSKD),* 4**,** 1-16.

JOHANSSON, M., ROUPÉ, M. & VIKLUND TALLGREN, M. From BIM to VR - Integrating immersive visualizations in the current design process. 2014. 261.

KREIDER, R., MESSNER, J. & DUBLER, C. Determining the frequency and impact of applying BIM for different purposes on projects. Proceedings of the 6th International Conference on Innovation in Architecture, Engineering & Construction (AEC), June, 2010. 9-11.

LI, B., ZHANG, R. & KUHL, S. Minication affects action-based distance judgments in oculus rift HMDs. 2014 2014. ACM, 91-94.

MAYLOR, H. 2010. *Project management,* New York; Harlow, England, Financial Times Prentice Hall.

MEZHER, T., ABDUL-MALAK, M. A. & MAAROUF, B. 1998. Embedding critics in decision-making environments to reduce human errors. *Knowledge-Based Systems,* 11**,** 229-237.

NCC. 2015a. Available: http://www.ncc.se. Accessed [2015-02-16]

NCC. 2015b. Available: http://www.ncc.se/vara-project/sca-huset-molndal/. Accessed [2015-02-17]

Rstudio.2015. Available: http://www.rstudio.se/project/ovrigt/sca. Accessed [2015-02-17]

RABIEE, F. 2004. Focus-group interview and data analysis. *Proceedings of the Nutrition Society,* 63**,** 655-660.

RAYUDU, C. S. 2010. *Communication,* Mumbai, Himalaya Publishing House.

ROUPÉ, M. 2013. *Development and Implementations of Virtual Reality for Decision-making in Urban Planning and Building Design.* Dissertation/Thesis, Chalmers University of Technology, Göteborg

SACKS, R., PERLMAN, A. & BARAK, R. 2013. Construction safety training using immersive virtual reality. *Construction Management and Economics,* 31**,** 1005-1017.

SANGER, J. 1996. *The compleat observer?: a field research guide to observation,* Washington, D.C; London, Falmer Press.

SCHAUFELBERGER, J. & HOLM, L. 2002. *Management of construction projects: a constructor's perspective,* Upper Saddle River, N.J, Prentice Hall.

SHANG, G. & LOW, S. P. 2014. *Lean construction management: the Toyota Way,* Singapore, Springer.

STEWART, R. A., MOHAMED, S. & MAROSSZEKY, M. 2004. An empirical investigation into the link between information technology implementation barriers and coping strategies in the Australian construction industry: 1. *Construction Innovation,* 4**,** 155.

WEIJERMARS, R. 2012. *Building Corporate IQ: Moving the Energy Business from Smart to Genius : Executive Guide to Preventing Costly Crises,* London, Springer London.

WOKSEPP, S. & OLOFSSON, T. 2008. Credibility and applicability of virtual reality models in design and construction. *Advanced Engineering Informatics,* 22**,** 520-528.

YE, J., SHULGIN, B. V. & RAJA, V. H. 2006. Virtual reality in construction industry: a requirement compatibility analysis approach. 2006 2006.

YEGER, H. 2015. The evolution of human communication. *Journal of Cell Communication and Signaling*.

YOUNG, M., GAYLOR, G., ANDRUS, S. & BODENHEIMER, B. A comparison of two cost-differentiated virtual reality systems for perception and action tasks. 2014 2014. ACM, 83-90.

Appendix

Interview protocol

A. Understanding and Communication

1) Could you describe your role and responsibility in the SCA-project?
   a) Experience? Number of years employed?

2) What communication mediums and tools do you use in your field of work?
   a) How do you think the different project participants understand your ideas?
   b) Are there visualizations tools used? (type of tool e.g. projector and your type of software used)

3) What decided that you take part in this project?
   a) How are you informed in the SCA-project?

4) Speaking about communication; encoding, transmitting and decoding information are fundamental parts of how different people interpret certain information. What do you think about the BIM HMD as a way of transmitting information from the virtual model?

B. Application of the BIM HMD in the design phase

1) Are you familiar with Building Information Models (BIM)?
   a) What is your experience with BIM visualisations?

2) What BIM-viewers have you used for viewing the BIM-models?
   a) E.g.: Solibri, Navisworks, Tekla BIM sight?
   b) Issues? Navigation with the mouse?
   c) How do you experience the navigation through the model?
      i) E.g.: easy/difficult, navigation to a specific place?

3) Could you describe your experience using the BIM HMD?
   a) Use (e.g. easy/difficult)
   b) Differences from on-screen visualization?
   c) Compatibility (e.g. technical support, computer performance, different working files)

4) How important is the level of realism when using the BIM HMD?
   a) Does visualizing the model at scale 1:1 make a difference?

5) To which extent can the BIM HMD complement your working environment?

6) How does the decision making process look like in the design review session?
   a) How much time is usually required to reach consensus?

b) To which extent can the BIM HMD help you collect data for the decision making process?

C. Implementation of a new technology in a project based organisation

1) What do you think is necessary to adopt a new technology in a project?
   a) Who are the driving actors for this adoption?

2) How can you determine if a new technology is adding any benefit?

3) How were you introduced to the BIM HMD technology?

4) How are you involved in using the BIM HMD technology?

5) How do you see the application path of BIM HMD in this project?
   a) Do you have any responsibility for its application?