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Authors: Kristian Kvalsvik & Morten Stien	Kristian Kvalsvik M Stien (signature of authors)
Internal supervisor: Knut Erik Bang External supervisor: Cecilie Irgens	
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Abstract

Projects in the construction industry are increasingly complex, involving collaboration between a wide range of stakeholders and specialized sections. Ambiguous communication between participants and misunderstandings about planned design are among the main causes for errors and budget overruns. The introduction of Virtual Reality (VR) presents opportunities to produce more realistic visualization by improving spatial perception for users, and has been shown to increase users' ability to uncover errors and deficiencies prior to construction. For companies, adoption of VR may potentially open new business opportunities and enhance current services. However, research shows that innovation in the construction industry is slow and that the adoption of new technology is perceived as difficult.

This thesis aims to identify how COWI may use VR to create value and how they may improve their VR capabilities. In order to answer this objective thoroughly, it has been broken down into three research questions:

- RQ0: What are valuable use cases for VR in COWI?
- RQ1: What is the current state of VR adoption in COWI?
- RQ2: What should be emphasized in order to increase COWI's VR capabilities?

These research questions are answered through a qualitative case study by conducting 12 interviews with COWI personnel, which are analyzed together with internal COWI documents and a thorough literature review.

The findings from the thesis present several use cases that can provide significant value for COWI if applied appropriately. The current state of VR adoption in COWI is characterized by varying degrees of competence within and between departments and sections. Vital information for implementation is present in the VR Community site on COWI's internal home page, but there is low awareness about the opportunities that are present. Several suggestions are provided for how COWI may improve their VR capabilities. The five main recommendations involve establishing a guideline bank for the use of VR, expanding the internal communication channels, developing VR facilities, establishing a centralized unit for governance of VR, and establishing informational feedback loops for experience gained through projects.

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Stavanger, June 14th. 2019.

Morten Stien

Kristian Kvalsvik

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Acronyms

Table 1: Acronyms

AEC	Architecture, engineering, and construction
AR	Augmented Reality
BIM	Building Information Model(ing)
CAVE	Computer-Assisted Virtual Environment
COWI-portal	Internal web-portal for COWI employees
HMD	Head-Mounted Display
MR	Mixed Reality
NDA	Non-Disclosure Agreement
R&D	Research and Development
RQ	Research Question
SID	Spatially Immersive Display
TAM	Technology Acceptance Model
VE	Virtual Environment
VR	Virtual Reality
XR	Extended Reality

1. Introduction

The construction industry has long faced criticism for lack of innovation, and many argue that lack of investment in R&D is one of the reasons the construction industry has seen a record low increase in productivity the last 20 years (Bughin, Manyika, & Woetzel, 2017; Proverbs, Holt, & Cheok, 2000). In order to increase efficiency, the industry has fragmented into smaller, more specialized sections (Bughin et al., 2017). This, however, sets high demands for communication and coordination both between the sections themselves and between the sections and the client. In the Proverbs et al. (2000) study of the UK construction industry, changes during the construction were identified as one of the main problems faced by the industry, which may indicate problematic issues regarding planning and communication between stakeholders.

In the last couple of years, there has been a drastic shift in the industry through digitalization in the form of Building Information Modeling (BIM). The use of BIM has had an overall positive effect across the industry and is considered to have improved collaboration and communication in a fragmented industry, and to have increased design quality by decreasing conflicts and rework (Campbell, 2007; L. Chen & Luo, 2014). Due to the data richness of BIM it does not only function as a tool for modeling, but as a high-value data pool which can facilitate interconnection of project data with other emerging technologies (Eadie, Browne, Odeyinka, McKeown, & McNiff, 2013; Sampaio, 2018). This creates a promising foundation for increased efficiency and productivity through further innovation and digitalization. One of those emerging technologies is Virtual Reality (VR), which firms in the industry have started to adopt.

However, the construction industry has a challenging environment for technology adoption, as projects become larger and more complex (Forbes & Ahmed, 2010). There is also a significant focus on short-term profit-maximization without considering the opportunity cost of slow technology adoption (K. Chen et al., 2017).

This thesis is a case study of COWI, a leading international consulting group within engineering, economics, and environmental science. The purpose of the thesis is to contribute to COWI's digital transformation by identifying where VR may create value, what the current state of VR adoption across the company is, and how to improve their VR capabilities further.

1.1 Background

The purpose of the following subchapters is to present the topic of interest in the perspective of the company involved and to give the reader an understanding of:

- Who COWI is and what they do
- How COWI is digitalizing their business
- The emerging use of VR technology in COWI

1.1.1 About COWI

COWI is a leading company within the AEC industry. It was founded in 1930 by the Dane Christen Ostenfeld. Today COWI has 7300 employees distributed over 90 offices in 25 countries, where 21 of these offices are situated in Norway. COWI is continuously involved in more than 12 000 projects across the world. They have a well-established competence within engineering, economics, and environmental science, and offer services across many different fields. The Norwegian branch of COWI specializes within Buildings, Water & Environment, and Transportation & Urban Development (Internal documents from COWI AS, 2019).

1.1.2 BIM in COWI

In the last couple of years, the construction industry has experienced an increased demand for the utilization of BIM through both new governmental regulations and customers/suppliers who expect the usage of BIM. In COWI, the need for digitalization and use of BIM has been widely acknowledged, and there has been a focus on increasing digital interaction and innovation. Today, most projects in COWI are carried out utilizing BIM (Internal documents from COWI AS, 2019).

1.1.3 VR in COWI

The high adoption rate of BIM in COWI has presented opportunities within other communication tools like Virtual Reality, Augmented Reality (AR), and Mixed reality (MR). In late 2016 COWI established a research study to evaluate the potential value of VR use in BIM projects for the construction industry and its clients. This study is still ongoing, but temporary results show that VR has the potential to substantially increase the quality of projects and improve the clients' overall experience. COWI has also started to implement VR in some of their projects, among others in the SUS 2023 project, where end-users have been able to see the model in virtual reality and give feedback on the design (Emborg & Sekse, 2018).

1.2 Scope and objective

The main objective of this thesis is to identify how COWI can use VR to create value and how they can improve their VR capabilities.

In order to answer this objective exhaustively it is broken down into three research questions:

- **RQ0: What are valuable use cases for VR in COWI?**
- **RQ1: What is the current state of VR adoption in COWI?**
- **RQ2: What should be emphasized in order to increase COWI's VR capabilities?**

The predominant part of this thesis is the analysis of research questions 1 and 2, which collectively aim at identifying how COWI can improve their VR capabilities. Research question 0 provides the foundation needed for this examination by identifying how VR can create value for COWI. When referring to value in this thesis, it is defined as advantages that can be gained both for COWI and for COWI's clients.

The research questions were answered by conducting a qualitative study. By interviewing key personnel in COWI, analysis was performed across two departments.

The scope had several limitations due to time constraints. This master's thesis is a 30 credits study, developed over a 22 weeks interval. COWI is a large company, and it was decided that the thesis should mainly focus on the Oslo and Trondheim offices. For simplicity, the authors will refer to COWI in this thesis when talking about the both of the Oslo and Trondheim departments. The Oslo office was chosen as the primary focus for investigation. Being the Norwegian headquarter, it was regarded as most representative for the organization among the Norwegian departments. The Trondheim department is included in order to see potential discrepancies between the offices and identify root causes for differences within COWI.

Due to the time-consuming nature of qualitative interviews, the number of conducted interviews were limited to twelve. Additionally, the literature review was limited to the areas regarded as most relevant for COWI and focuses primarily on VR in the design phase of a construction project. Other potential use cases, such as the use of VR technology for training of internal personnel or use of VR during construction, have not been considered in this thesis.

2. Theory

The purpose of this chapter is to provide the theoretical foundation of the thesis. Several topics and terms that are important to understand in order to answer the research questions are elucidated here.

2.1 Digitalization

Transformation of processes through digitalization has become a high priority for businesses in the last couple of years. In order to sustain a market leader position in a digital world, a company needs to be capable of adapting to new technology and market trends quickly. Companies that are unable to meet demands in a fast-changing and dynamic business environment will struggle to stay competitive (Kerravala & Miller, 2017).

2.1.1 How digitalization effects businesses

Digitalization can affect a business in different ways. Parviainen & Tihinen (2017) points out that it can change the entire operational environment and internal functionality. It can also create new business opportunities, change roles in a value chain, and end existing business. Thus, the goal of digitalization and the impact it has can be identified from three different viewpoints: Internal efficiency, External opportunities, and Disruptive change (Parviainen & Tihinen, 2017).

Internal efficiency

Through digitalization one can improve internal efficiency. This improvement in efficiency can be achieved by restructuring internal processes and improve workflow through digital tools. Some of the potential benefits from using digitalization for internal efficiency is to improve the efficiency of current business processes, quality, and consistency by increasing the accuracy and eliminating manual steps (Parviainen & Tihinen, 2017).

External opportunities

New business opportunities can arise from digitalization, e.g. by providing a new service to an existing customer. New digital technologies can help a company improve its current value proposal towards their client as well as creating new areas of value for new and existing customers (Parviainen & Tihinen, 2017).

Disruptive change

The last viewpoint is when digitalization causes changes to the whole business and its core capabilities. This type of digitalization is called disruptive change and can cause whole businesses to become obsolete over a short period of time (Parviainen & Tihinen, 2017). Using VR in construction projects is currently introducing incremental changes to existing processes, and the focus of this thesis will, therefore, be centered on the internal efficiency and the external opportunities of this technology. How VR may increase efficiency or present an external opportunity in the construction industry is further elaborated in chapter 2.3.1.

2.1.2 Digitalization in practice and change management

When introducing a new digital tool like VR, it is not enough to have the technology available. It needs to be used in a meaningful way that creates value. This often introduces the need to change current routines and do things in new and different ways. Holloway & Carusi (2015) point out that change in an organization will be met with resistance from employees in the organization; this is elaborated under chapter 2.1.2.2. For a change in an organization to succeed it is essential to understand what drives the change, and how resistance can be met in order to manage the change in an effective manner (Holloway & Carusi, 2015).

2.1.2.1 Drivers of change

There are many different drivers of change within an organization. According to Jacobsen (2018), citing Van de Ven and Poole (1995), change drivers can be described as a profoundly different underlying mechanisms and sequences of events that inform how and why change exists. Two common types of change drivers are top-down and bottom-up. In top-down, upper management in an organization are the ones who are seen as the main driver of change. This differs from bottom-up were the main driver of change is the company employees.

A study from Arayici et al. (2011) about lean BIM implementation in the construction industry concludes that a bottom-up approach is more effective than a top-down approach when implementing new technology like BIM. They argue that although the technology itself is a vital part of technology adoption, the people and processes of the organization are as important during change. Arayici et al. further argue that through a bottom-up approach, employees are more engaged and involved in the change, leading to employees being more positive towards adoption than in a top-down approach. A bottom-up approach helps to build organizational capabilities through employees learning new skills and gaining new knowledge, as well as reduce resistance to change from employees (Arayici et al., 2011).

Birkinshaw, Bouquet, & Barsoux (2011) agrees with this but argues that a bottom-up approach only covers the first part of successful technology adoption. According to their study in order for a bottom-up initiative to succeed in the long run, it needs to be picked up by upper management in order to align it with long term business goals and distribute necessary resources. A technology adoption initiative increases its chances of being successful when it can gain the necessary practicality and traction among personnel from being a bottom-up initiative, as well as the necessary resources and business alignment from management (Birkinshaw et al., 2011).

2.1.2.2 Change resistance

In most cases, change in an organization follows the model of human grief induced by Elizabeth Kübler-Ross in 1960. Her model is the foundation of the classic change curve developed by Schneider and Goldwasser (1998). The change curve, shown in figure 1, describes employee performance during a process of change. It displays that there is typically a drop in performance during a process of change, which makes implementing changes harder. The variation in performance during a change process is often due to how employees feel regarding the change. Therefore, the resistance that management may experience from employees during change processes is highly connected to how employees feel about the change (Murray & Richardson, 2003). Nikula, Jurvanen, Gotel, & Gause (2010) have further validated that the change curve, shown in figure 1 represents changes introduced by new IT-tools and systems, confirming that a company can experience a drop in performance when implementing new IT tools, making implementation more challenging.

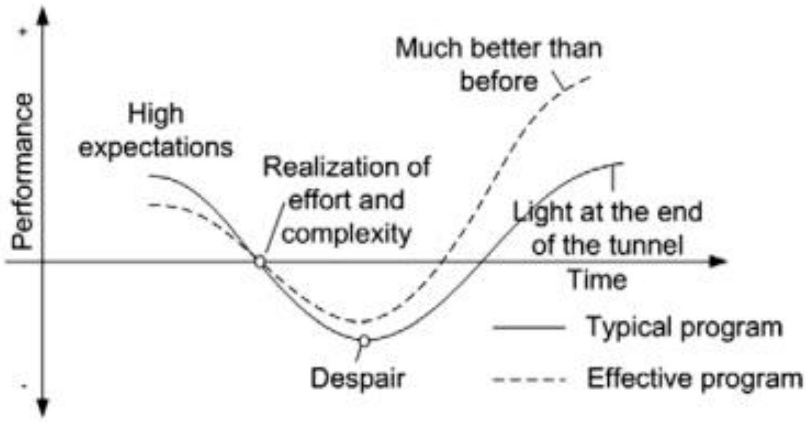

Figure 1: The Classic Change Curve. Shows performance during a process of change for a typical and an effective change program. From Nikula et al. (2010), originally from Schneider & Goldwasser (1998).

According to van den Heuvel, Demerouti, Bakker, & Schaufeli (2013), change can only be successful when it is supported and implemented by the change-recipients. Because changes in an organization are becoming more and more common in today's business world, van den Heuvel et al. argue there is a need to look beyond the traditional attitude of employees as a source of resistance and instead focus on improving the employees' ability to adapt towards change. This will, in turn, increase the organization's ability to change (van den Heuvel et al., 2013).

According to the study from van den Heuvel et al., change information and meaning-making affect the employee's ability to adapt to changes. Change information is how well information about the change is communicated to employees (van den Heuvel et al., 2013) and is linked with higher openness to change (Wanberg & Banas, 2000) as well as having a reducing effect on change resistance among employees (Oreg, 2006). Meaning-making, on the other hand, refers to the employee's ability to understand why the change is happening and that they are finding the change meaningful (van den Heuvel et al., 2013).

As shown in figure 2 the study found that change information is positively correlated with meaning-making, adaptive attitudes, and adaptive behavior, whereas meaning-making is positive correlated to adaptive attitudes and adaptive behavior over time (van den Heuvel et al., 2013).

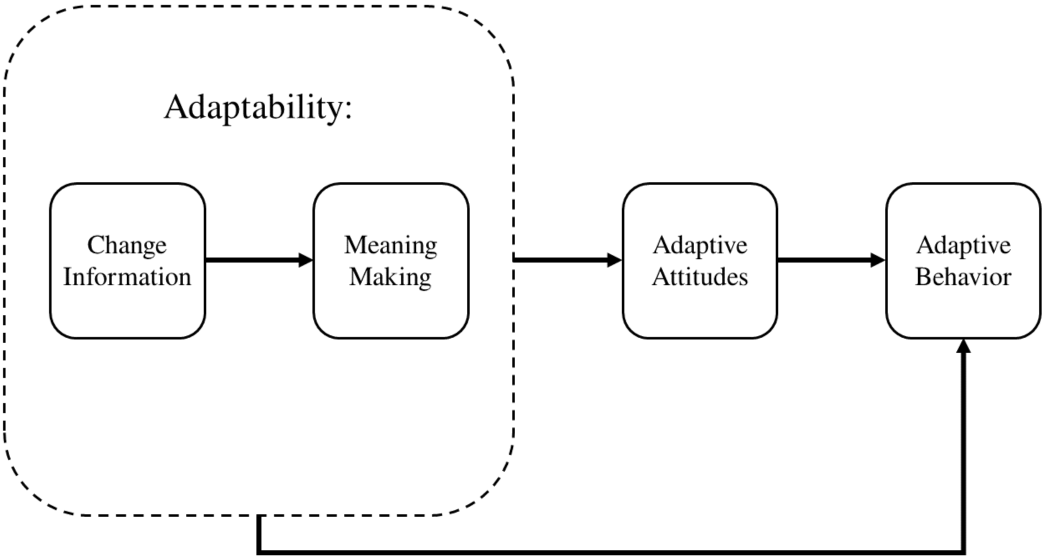

Figure 2: Change resources adaptation model. Showing relationship between Change Information and Meaning Making with Adaptive Attitudes and Adaptive Behavior. Adapted from van den Heuvel et al., (2013).

Van den Heuvel et al. (2013) highlights the importance of proper communication from management to employees at all stages of a change process. Information given before the change process is shown to have a positive effect of the employees' ability to understand the meaning of the change during the change process, while information given during the change process positively affects the attitudes of the employees towards change after the change process. Employee participation and feedback is vital for successful change as they are the ones that ultimately have to conduct the change, and management should strive to involve employees as much as possible through information, communication and participation as this will help employees meaning-making and in turn the adaptability of the organization (van den Heuvel et al., 2013).

The study also showed that meaning-making both before and during the change process correlated with adaptive behavior, emphasizing the importance of employees finding the change to be meaningful as they were more adaptive to the change (van den Heuvel et al., 2013). The model introduced by van den Heuvel et al. has a resemblance to the technology acceptance model which emphasizes the importance of how employees' perception of usefulness and ease of use effects adaptation of new technology. This model is further elaborated in chapter 2.1.3.2.

2.1.3 Technology adoption

The adoption of technology has received a lot of attention in academic research, and consequently many theories exist on this subject. Amongst the most acknowledged and cited is Rogers' (1995) Innovation Diffusion Theory, concerning diffusion as a process of communication where users are informed about the availability of new technology and are convinced to adopt (Attewell, 1992). This subchapter addresses Innovation Diffusion Theory, supplemented with the Technology Acceptance Model, which concerns the user's actual acceptance and utilization of implemented technology.

2.1.3.1 Innovation Diffusion Theory

Figure 3 illustrates the factors Rogers (1995) features as most important for the rate of adoption of innovations. More than half of the variance he found in the rate of adoption is explained by the five primary attributes: Relative advantage, compatibility, complexity, trialability, and observability. Rogers' description of compatibility is not included in this thesis to avoid confusion, because compatibility is described with a differing interpretation elsewhere in this thesis.

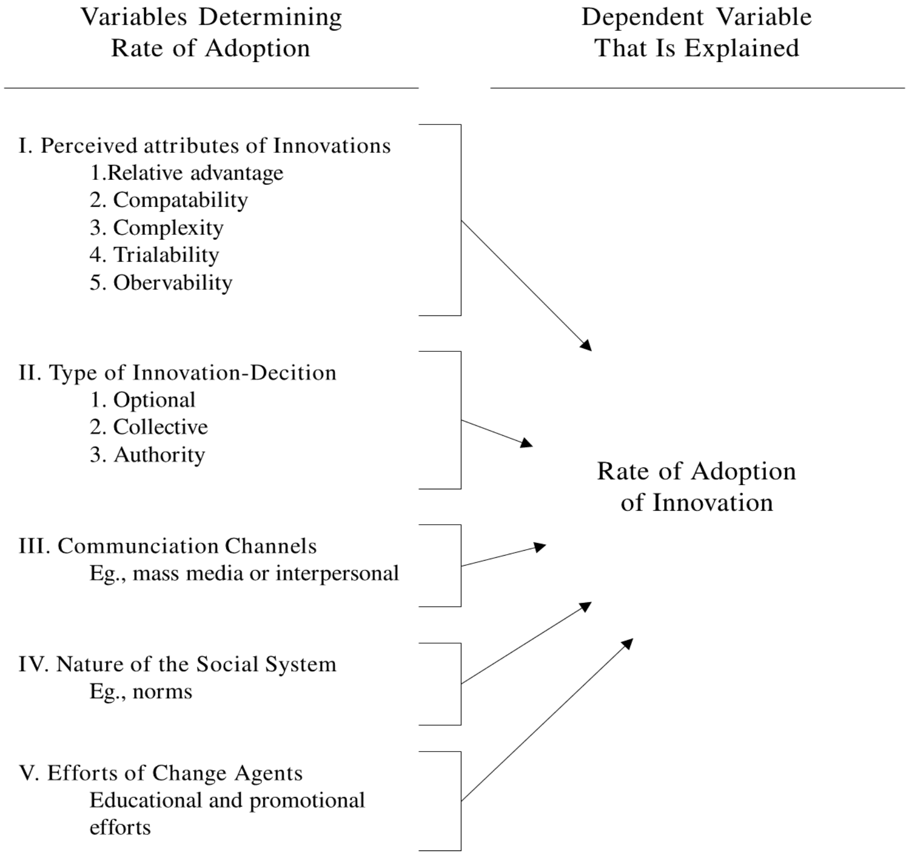

Figure 3: The Innovation Diffusion model. Adapted from Rogers (1995)

Relative advantage is defined by Rogers (1995) as “the degree to which an innovation is perceived as being better than the idea it replaces” (p. 212). It is necessary for potential users to understand how the innovation may cause improvements to the current situation.

Furthermore, Rogers (1995) describes complexity as the degree that an innovation is experienced as difficult to understand and use. That is whether or not new technology has a precise meaning to potential users. The user’s perceived complexity is negatively correlated to the rate of adoption. Excessive complexity of technology can therefore be a substantial obstacle for adoption (Sahin, 2006).

Trialability refers to the degree that an innovation can be experimented on a limited basis. Innovations are generally faster adopted when they are available for testing in the user’s surroundings. The process of trying out new technology is a way to establish meaning of the implementation for the user, understanding how it works on a personal plan (Rogers, 1995). The rate of innovation is positively correlated with the extent to which an innovation is tried (Sahin, 2006).

Observability is described as the degree to which the results of an innovation are visible to others. Some technology creates changes that are easy to observe and communicate, while other technologies yield results that are not easily measurable. Observability has a positive correlation with the rate of adoption (Rogers, 1995).

Furthermore, Rogers emphasizes that the type of innovation-decision used is correlated to an innovation’s rate of adoption. New technology that requires optional decisions for users to implement is usually adopted faster than when adopted by an organization. Having more persons involved in the decision to implement technology leads to slower adoption. A measure for stimulating the rate of adoption is to alter the number of persons involved in the innovation-decision (Rogers, 1995).

Another factor Rogers highlights that can affect the rate of technology adoption is the type of communication channels used to diffuse an innovation. If utilizing interpersonal communication channels rather than mass media channels for creating awareness of an innovation, the adoption rate is usually reduced. It is crucial that the type of communication channel used is seen in context with the type of technology. For less complex innovations, the use of mass media channels is generally more beneficial for diffusion of knowledge (Rogers, 1995).

The two final factors featured in figure 3 include the nature of the social system and the extent of change agents' promotion efforts. These are not elaborated, as they are not discussed later on in the thesis.

2.1.3.2 Technology Acceptance Model

Comparable to how traditional diffusion research focuses on the individual's innovation adoption-decision, studies using the Technology Acceptance Model (TAM) focus on the individual users' acceptance and actual use of technology. TAM is an extensively used model for predicting the use and acceptance of IT in organizations (Davis, 1985, 1989). This model (shown in figure 4) is built on a foundation of theory concerning human behavior but is tailored particularly towards information technology. The significance of this model has been empirically substantiated through later research (King & He, 2006). The model consists of four main areas: Perceived Usefulness, Perceived Ease of Use, Attitude Towards Using, and Actual System Use.

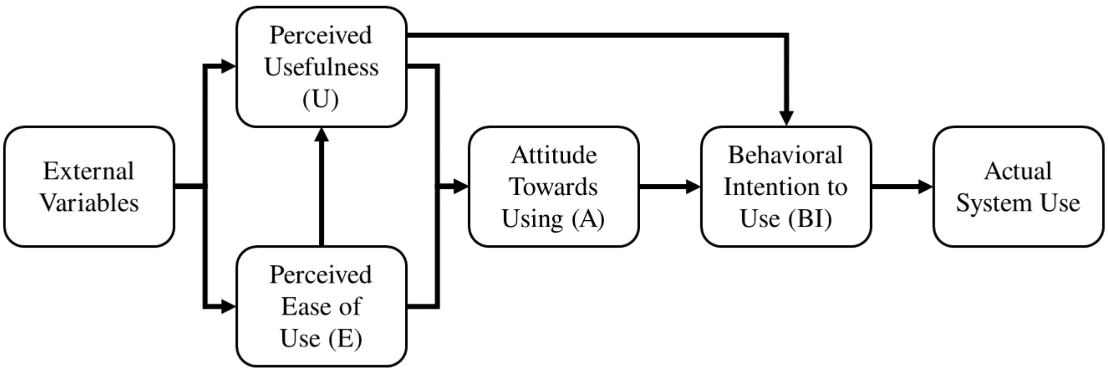

Figure 4: Technology Acceptance Model Adapted from Davis, Bagozzi & Warshaw (1989, p. 985)

The TAM proposes that a user's attitude towards use is jointly determined by how the user perceives the usefulness-, and ease of using a system. Perceived usefulness is defined by Davis et al. (1989) as "the degree to which a person believes that using a particular system would enhance his or her job performance", while perceived ease of use is defined as "the degree to which a person believes that using a particular system would be free from effort" (p. 985). TAM suggests that these two elements are jointly decisive for a user's attitude towards using a system. Further, attitude towards- and perceived usefulness of a system jointly determine the intention to use, which in turn determines actual system use (Davis et al., 1989).

2.1.4 Building Information Models

Globally, the construction industry is lagging behind other manufacturing sectors in terms of applying digitalization into production and management (Sharma, Gröne, de Souza, & Koster, 2011). The introduction of Building Information Models (BIM) represents a new paradigm within the architectural, engineering, and construction industry (Azhar, 2011). BIM is described as a digital representation of the building process to facilitate exchange and interoperability of information in digital format (Eastman, Teicholz, Sacks, & Liston 2008).

BIM technology enables virtual models of buildings to be constructed digitally. The building information model can be utilized for both design, planning, construction, and operation of the facility. The model assists engineers, architects, and stakeholders to visualize the construction in detail before it is built to identify potential issues regarding design, construction, or operation (Azhar, 2011).

2.2 Virtual Reality

Virtual Reality is a term widely used and the understanding of the term may differ. VR is often used as an umbrella term for many different immersive experiences. This includes similar terms like augmented reality (AR), extended reality (XR), and mixed reality(MR) (Mealy, 2018). According to Burdea & Coiffet (2003) VR can be described as "a high-end-user-computer interface that involves real-time simulation and interactions through multiple sensorial channels" (p. 3). Another definition from Mealy (2018) is that VR can be defined as "an immersive computer-simulated reality that creates a physical environment that does not exist" (p. 9). Though there are some differing definitions it can, in short, be described as a tool for interacting with three-dimensional data in real-time (Whyte & Bouchlaghem, 2002).

VR differs from AR in that VR is typically closed off from the real world and by that introducing the user to a new environment, as AR typically adds an overlay of computer-generated content on top of the real world (Mealy, 2018). However, it is believed that these technologies will merge to a large extent into the hybrid mixed reality (MR). MR gives the user the possibility to interact with the data in real-time from VR and a possibility to go back and forth between a fully simulated environment to an overlay of data generated content on top of the real world (Mealy, 2018). In this thesis, the authors have chosen to focus solely on VR technology. VR is the chosen modality due to being the most commonly adopted in the AEC industry, making it better suited for a case study, as well as scope limitations.

2.2.1 VR systems

Due to the many definitions of what VR is, there are many different systems that can be regarded as VR (Thabet, Shiratuddin, & Bowman, 2002). In this thesis, the authors have chosen to focus on "immersive VR". It is defined by Thabet et al. as having the virtual environment to some extent, surrounding the user. Immersive VR is what most think of regarding VR, as well as the most widely adopted in the construction industry. There are also different types of immersive VR based on the level of immersion and the type of display used for visualization (Thabet et al., 2002).

2.2.1.1 Hardware

There exists a large amount of different output and input devices for immersive VR systems. Output devices include visual and auditory. Input devices include, among others, movement sensors and handheld controllers (Thabet et al., 2002). Hardware devices that are considered relevant by the authors for this thesis are described in the following chapters.

Spatially immersive display

One approach that Thabet et al. highlight for displaying immersive VR is Spatially Immersive Display (SID), which is to surround a user with displays. A common type of SID, which is used in the construction industry today, is the Computer-Assisted Virtual Environment (CAVE) set up. A CAVE uses 4-6 projectors in the shape of a cube/hexagon in order to create an environment the user can walk into. The CAVE allows for multiple viewers, making it ideal for presentation, but usually, only one user will have the correct perspective view. A drawback, however, is that SIDs and CAVEs are costly and usually not fully immersive (Thabet et al., 2002).

Head-mounted displays

Another display method for immersive VR is the use of Head-Mounted Displays (HMD). It consists of two small screens that are mounted inside a wearable helmet. The two screens are controlled separately, allowing for stereo graphics. In addition, a head tracer measures head movement, allowing intuitive change of view (Thabet et al., 2002). After the launch of the first Oculus Rift in 2013 HMD experienced substantial growth, with large tech giants developing competing solutions. There are several levels of immersion to HMD, and the market generally differentiates between high-end devices, mid-tier devices, and low-end devices (Mealy, 2018).

High-end

Dominated by HTC Vive and Oculus Rift, high-end devices offer a room-scale experience which enables the user to move about in the physical space and have the movements reflected in the virtual environment. They offer a wide field of view, allowing for a high degree of immersion. An external computer usually powers them, and most of them are compatible with motion controllers (Mealy, 2018).

Mid-tier

Typical for mid-tier headsets is the use of a smartphone as the display. This means compromising immersion for a lower price. They generally have a smaller field of view and slower refresh rate than high-end devices. They are often compatible with a single motion controller. However, they do not offer any room-scale experience and do not track movement other than head rotation and orientation (Mealy, 2018).

Low-end

As the mid-tier headsets, low-end headsets are also powered by a separate smartphone. Due to the simple design requirements, there are many different low-end solutions. They share a similar lens set up, and due to lacking controllers for interacting with the virtual environment, they are limited to function as VR "viewer." The simplicity also means that the cost associated with the headsets is minimal (Mealy, 2018).

2.2.1.2 Software

There are large amounts of VR software being developed and presented in the market. It is necessary to be conscious of the company's requirements before choosing one. There are many factors to consider regarding VR software in addition to effecting 3D object generation, navigation, and interaction. Other features like compatibility with other systems, optimization of the level of detail, collision detection, multi-user possibilities, and object scaling are decided by software choice, meaning that choice of software needs to correlate with features needed (Thabet et al., 2002).

2.3 VR in the construction industry

The construction industry, in general, is regarded as conservative and reluctant to embrace new technology (Sundukovskiy, 2018). The overall picture in Europe and the US shows that construction is the least digitized sector (Sharma et al., 2011). This lack of technology adoption and renewal is listed as one of the main reasons why the industry is trailing behind in productivity with only 1% annual productivity growth over the last 20 years (Bughin et al., 2017). However, there is a shift towards becoming a more digitalized industry. In the last couple of years, the introduction of BIM as a tool has assisted the industry by eliminating inefficiencies and redundancies, improving collaboration and communication and increasing overall productivity (Sampaio, 2018). By becoming digital and data-driven through BIM, the industry opens up for other emerging technologies (L. Chen & Luo, 2014).

VR is one of the emerging technologies that have been linked closely as a possible extension to BIM. Combining the easy accessibility, interoperability, and ability to create and manipulate design data from BIM with visualization and interactivity from VR (Sampaio, 2018). For this reason, software companies have started to develop advanced products that close the gap and link VR devices and software with BIM (Sampaio, 2018).

2.3.1 Business drivers

There are many different business drivers for VR in construction with varying potential for value creation and impact (Whyte, 2002). These business drivers are ways VR can improve current processes [2.1.1, para 2] or create new business opportunities [2.1.1, para. 3] dependent on how VR is used and for what purpose (Parviainen & Tihinen, 2017). According to (Sampaio, 2018) VR application is likely the next step for BIM due to the possibility of seamless connection into the design process and ultimately improving the entire built environment. In addition to the potential value in the design process, VR introduces potential value creation in areas like marketing and sales (Whyte, 2002). Whyte (2002) presents several business drivers for the use of VR in the construction industry:

- Project team – Client collaboration
- Co-coordinating in the project team
- Simulating dynamic environment
- Marketing
- Demonstrating tech competence

2.3.1.1 Project team – Client collaboration

According to Kodama (1995), clients often need change as they discover rather than know what they need, and the client's initial priorities are not the best ones. This means that decisions made from a thorough brief at an early stage may prove to be insufficient in covering the client's needs. Because the client's needs are being discovered rather than known, it is necessary to review design throughout development and adapt to emerging needs (Whyte, 2002). Zimmerman & Martin (2001) argues that users evaluate the built environment in a different way than designers. In addition, many users lack experience with reading 2D/3D models (Sampaio, 2018). By overlaying a BIM model with VR and conducting walkthroughs/reviews of design, communication between the project team and client can improve as it makes it easier for clients to visualize design at an earlier stage. This will support decision making and potentially reduce cost and time by eliminating rework later in the project (Sampaio, 2018).

By allowing clients and end-users to participate in the design, experiences from the users can be fed back to the design team. It is important that all groups of future users are involved in design review to ensure the needs of all future occupants are met (Whyte, 2002). According to Derbyshire (2001), one challenge with end-user involvement in design is resistance from the designers themselves. Bias from designers regarding how they want to design buildings might not align with the needs of the client (Derbyshire, 2001). Participatory design reviews can be seen as a way of doing reality checks through the project were designers can align their views with the occupant's needs, and in turn function as a protection for the interest of the end-users (Leaman & Bordass, 2001).

2.3.1.2 Co-coordinating in the project team

Amongst the large companies in the construction industry, the organization often consists of many fragmented disciplines. This fragmentation enables the disciplines to specialize but makes the organization complex and makes collaboration challenging. This complexity sets high demands for efficient and effective communication in order to decrease the chance of misunderstanding and maintain productivity (Bughin et al., 2017).

Due to the many different disciplines and stakeholders that need to collaborate during a project, where design and requirements can change rapidly, there is a need for agreement on one version of "the truth" of content in 2D/3D models for effective collaboration (Bughin et al., 2017).

According to Campbell (2007), the adoption of BIM can assist the integration of the fragmented industry. By utilizing BIM, companies can eliminate inefficiencies, improving collaboration and communication, and in turn, improve productivity (Campbell, 2007).

By adding VR, the BIM solution can increase efficiency on communication and problem-solving in an interactive and collaborative project (Sampaio, 2018). Jiao, Zhang, Li, Wang, & Yang (2013) further states that VR technology leads to better cross-discipline communication in the building sector, based on better design visualization, contributing to a better understanding of the project.

In addition to aligning views on a model in different disciplines in the project group, VR can also help the scheduling process as an extension to 4D BIM as a way of enhancing construction planning (Sampaio, 2018). Having the opportunity to visualize construction site in VR issues connected to clashing operation on-site can be detected before construction has started, and scheduling can be optimized, reducing the length of the construction process (Whyte, 2002). This will cut time and cost wasted on-site (or later in the design phase), and lower the overall design and construction cost of the project (Whyte, 2002).

2.3.1.3 Simulating dynamic operations

One important aspect of BIM is the ability to simulate use of the model. According to (Thomke, 1998) the cost and time of experimentation can be cut through computer modeling, allowing for more iterations, which again can improve learning. Whyte (2002) highlight that these simulations can be enhanced by the use of VR. By simulating dynamic operations, one can get a better understanding of how the environment supports/hinders the operation that is going to be conducted (Whyte, 2002).

This is highly relevant for design testing of complex projects where the time and cost of other types of testing (mockups, etc.) can be considerably higher. By using VR and digital prototypes, several aspects can be simulated, which includes the *movement of people*, *movement of vehicles,* and *operational logistics* (Whyte, 2002). According to Whyte, one can improve the quality of the final product by exploring the operation of design alternatives.

2.3.1.4 Demonstrating tech competence

A business driver of VR in construction identified by professionals is demonstrating technical competence. By displaying a project in VR, one can differentiate from the competition and win bids. Demonstrating technical excellency when negotiating can help consultant engineers and project managers to win over a client's trust and in turn, generate more business for the company (Whyte, 2002).

Using VR in the sales process has become common in some housebuilding companies in Japan where 60% of VR the usage is done before the customer has purchased a home. The use of VR in this early stage can also help reduce the potential for problems that arise from the ambiguity of the project scope between the company and customer (Whyte, 2002).

2.3.1.5 Marketing

Another business driver for VR is marketing. It has become commonplace for companies to use VR models from earlier/current projects to market themselves. VR still has novelty value, and one can leverage VR models to create enthusiasm and press coverage surrounding a project (Whyte, 2002).

VR models may also be used as marketing for the clients themselves. This has been especially useful in large complex projects like airports or banks, where the client wants to use VR to market the new facility. It has also been used for virtual tours of a new facility in order to advertise rental space for a prospective customer and potentially increase profitability for the client (Whyte, 2002).

Companies in the construction industry which have adapted VR often see a high novelty value and regard VR as beneficial in marketing. VR is able to move the focus from glossy images and architectural design to the spatial layout of a new building, the potential for change over time, and improved running of efficient construction (Whyte, 2002).

2.3.2 Valuating VR in construction

VR investments are usually minor in comparison to the full construction project cost and can have significant positive implications on the profitability (Woksepp, 2007). However, these implications are usually in the form of increased quality of the construction design or new solutions that are difficult to value in terms of money. DeLone & McLean (1992) reason that conventional cost-benefit analyses are often not performed for this kind of technology because of difficulties in quantifying intangible benefits.

However, there is existing research quantifying certain benefits of using VR for improving decision making in projects. A research project by Paes, Arantes, & Irizarry (2017) compares users' perception of architectural models when using an immersive environment, to the perception gained when using traditional computer screens. The study indicates that the immersive environment can benefit current design practices by providing a better overall spatial perception of the 3D-model when using the immersive environment. This includes statistically significant results showing that users are able to better estimate distances and make more sense of spatial information. However, a better perception of the design of the model does not necessarily mean that the user's ability to make effective design decisions is improved. (Paes et al., 2017).

Another study concludes that the use of immersive display systems in project meetings leads to uncovering more ideas because of a shift in conversation types from being descriptive to being of more predictive character as shown in figure 5. This, in turn, led to savings in time and money (Maldovan & Messner, 2006).

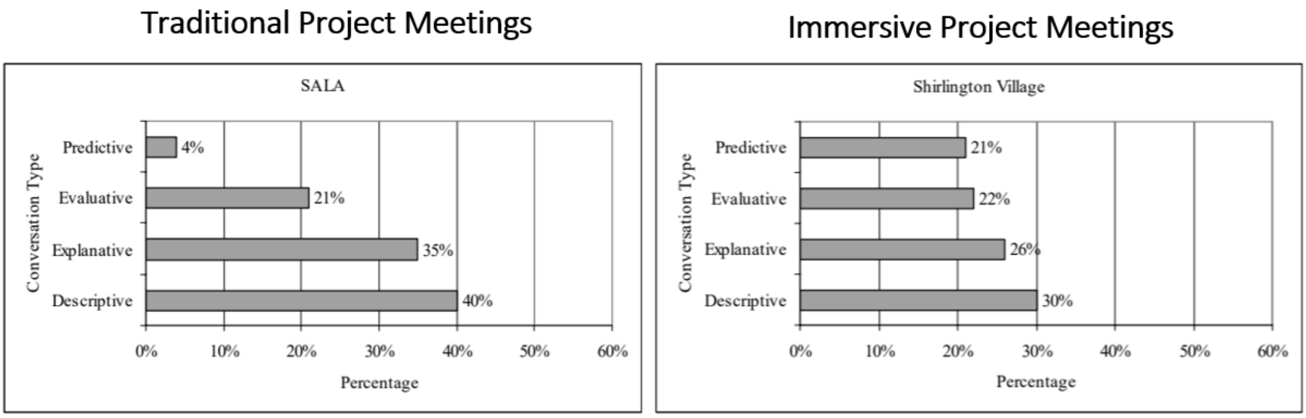

Figure 5: Difference in nature of conversation with and without immersive visualization in construction project meetings. From Maldovan & Messner (2016).

2.4 Implementation of VR technology in an organization

A report from 2018 (Cohen et al., 2018) identifies four key focus areas for successfully implementing/-enhancing the use of VR and AR technology in a company:

- Focus on identifying the 'right' use case that provides lasting value and support employees on this journey.
- Upskill internal workforce and recruit for VR skills.
- Develop a centralized governance structure with all VR activities coordinated by a team and build VR awareness.
- Prepare technology infrastructure to integrate VR.

2.4.1 Use cases

Providers of VR technology says that organizations are eager to try out the technology before knowing how to apply it. Many organizations have difficulties with identifying when and how to use VR technology (Cohen et al., 2018). According to Forni (2017), the first step for successful VR implementation is researching the possibilities that exist for the organization's business processes. Furthermore, it is necessary to focus on how VR can improve specific processes before proceeding to the development of VR facilities (Forni, 2017). A study from 2006 about VR adoption in the construction industry highlights internal needs as a key for adoption (Fernandes, Raja, White, & Tsinopoulos, 2006). Research has shown that finding the right use cases and testing its applicability is part of the top three priorities for companies that succeed with implementing VR (Cohen et al., 2018).

2.4.2 Workforce competency

There is a growing gap between digital skills needed and skills possessed by organizations (Buvat et al., 2013). Many organizations argue that "their digital talent gap is hampering their digital transformation programs and that their organization has lost competitive advantage because of a shortage of digital talent" (Buvat et al., 2013, p. 4). This is also applicable to VR technology, which is quite new and where many companies lack in-house VR expertise (Cohen et al., 2018). According to Fernandes et. al. (2006), the skills of project teams is one of the essential factors for the adoption of VR in construction companies.

Companies that are succeeding with VR technology have focused greatly on the necessary skillset. One way of upskilling the workforce is by investing heavily in an agile, in-house team of experts. This can be achieved both by hiring new personnel with VR expertise or by conducting specialized in-house training for current employees (Cohen et al., 2018). For training of personnel, being interested in VR and new technology is vital as (Hidi, 1990) argues that interest is central in determining how people select and persist in processing information.

Brand (2015) further reasons that an important element in successfully implementing change is creating a knowledge transfer plan. More than just training, this should account for the different ways people can acquire the knowledge they need to make the system a success. This knowledge transfer can include desktop procedures, expert users, interactive FAQs, help desks, coaching, or classes (Brand, 2015). Furthermore, Davies & Hobday (2005) argue that organizational knowledge resides in its memory, which is located in the established routines. These patterns for productive activities form the basis for the organization's capabilities (Davies & Hobday, 2005).

Although there are various definitions of "learning in organizations," they all have a knowledge component and an action component in common (Jacobsen & Thorsvik, 2007). Traditional theory about learning is that people are motivated by goals and that learning involves efforts to change behavior to become better at achieving these goals. Argyris & Schön (1978) show that there is a fundamental difference in the learning that considers *how* procedures can be improved, and learning that also addresses *why* it should be improved. He differs between Single-loop learning and Double-loop learning as shown in figure 6. Single-loop learning is described as the learning where the goals and values behind the behavior are taken for granted. It is not questioned whether this goal is really what is wanted, it is only focused on how the result can be improved. Double-loop learning, however, involves a constant will to assess and question the goals and values that form the basis for the behavior (Argyris & Schön, 1978).

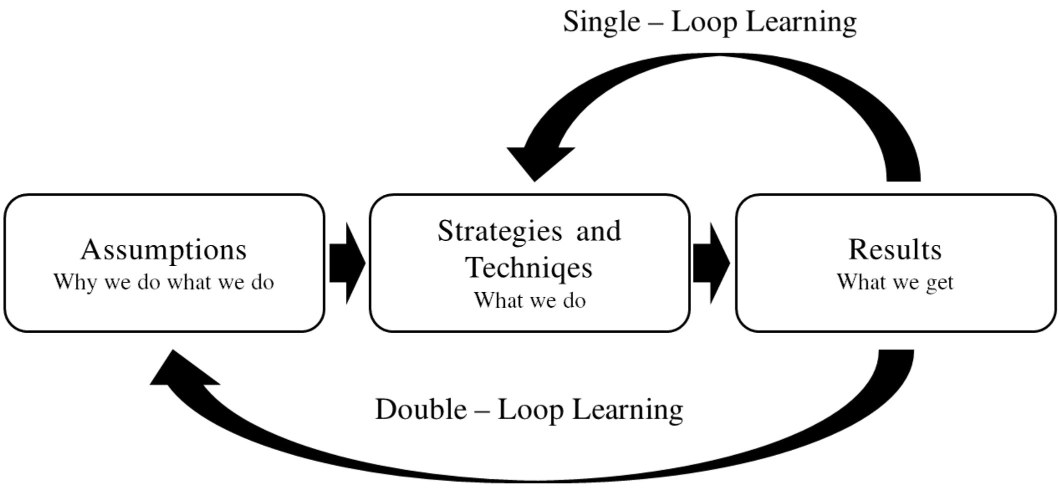

Figure 6: Single- and double-loop learning. Adapted from Argyris & Schön (1978).

It is also emphasized the distinction between explicit and tacit knowledge and their ability to be disseminated. Explicit knowledge can be formally expressed and learned from other people. This is information that can be transmitted between people through writing and can be presented in manuals, procedures, and guides. Tacit knowledge concerns knowledge gained through personal experience. This is knowledge that cannot be articulated and is embedded in skills and teamwork of personnel (Davies & Hobday, 2005).

An alternative way for organizations to gain required skills is by outsourcing to subject matter experts, or partner with specialized teams and institutions in order to leverage outside talent (Cohen et al., 2018).

2.4.3 Governance

Support, training, and encouragement from top management are vital for communicating the value of VR to workers. This is needed in order to overcome change resistance and increase the VR adoption rate (Cohen et al., 2018; Fernandes et al., 2006). Fernandes et al. (2006) also argues that top management support is central for gaining the necessary capital and labor resources needed for the implementation of VR within an organization.

In order to let the technology develop and flourish within the company, one must establish a governance structure. There are many key stakeholders regarding the use of VR technology in a company, often across different parts of the company (Cohen et al., 2018).

Many believe that innovation and implementation of new technologies should most ideally be carried out through bottom-up initiatives. This perception stems from top management being distanced from the day-to-day tasks, making it challenging to identify needs (Birkinshaw et al., 2011). However, it is vital that top management picks up these initiatives and support further development, allocates resources and aligns initiatives with business goals (Birkinshaw et al., 2011; Cohen et al., 2018). In addition to ensuring the best use of resources, Cohen et al. (2018) highlights the importance of a centralized unit that can store and share knowledge about VR throughout the organization. This information spreading is vital when adopting VR as companies often struggle with a general lack of awareness of VR technology, its application, and the benefits that it can yield, which in turn makes adoption difficult (Cohen et al., 2018).

Another way of spreading knowledge and increase VR awareness is through employees championing for VR technology (Fernandes et al., 2006; Cohen et al., 2018). A study by Fernandes et al. (2006) about VR adoption in the construction industry concludes that the existence of champions is critical for succeeding with widespread VR adoption. Fernandes et al. further states that champions can convince associates, subordinates, and top management of the benefit of VR in construction.

A central part of the top management role in implementing new technology is aligning the implementation of technology with business goals (Birkinshaw et al., 2011). This requires top management to have a strategy. Although the technology itself is important, value is created through how well it is integrated in the company. Therefore, having a strategic focus is vital for gaining long-term value from implementing new digital technology. This means that top management needs to understand how the new technology can be used to affect business and be willing to lead the way in conceptualizing how the technology may transform the industry (Kane, Palmer, Phillips, Kiron, & Buckley, 2015). However, it is recommended that a high-level digital strategy is developed and that new technological tools are seen in light of this, aligning technology use towards long term business goals and not developing individual strategies for all new technologies (Kane et al., 2015).

2.4.4 Technology infrastructure

A large part of companies that are exploring and implementing VR technology believe that complexity in execution, as well as lack of data and technology readiness, is a significant barrier for adoption. According to a Cohen et al. (2018) companies should ensure that technology building blocks are in place.

It is given that in order to use VR, necessary hardware and software need to be available for personnel in the company. It is also imperative to have available data in the right format ready for use. Having the right data available is fundamental for implementing VR technology (Cohen et al., 2018).

In order to decrease the complexity of execution, companies can collaborate with other experienced vendors. These vendors have standardized solutions, which can help move from specialized solutions for all use cases to a solution that can be applied to most or all use cases. Partnerships with universities for further developing technology and testing potential use cases should also be considered (Cohen et al., 2018).

3. Methodology

The purpose of this chapter is to explain the methodology used for this thesis. It describes the research strategy, research design, research method, data analysis, and quality of study.

3.1 Research strategy

For this thesis it is primarily chosen an inductive and qualitative research strategy. This strategy was opted for in order to understand what valuable use cases there are for VR in COWI, what the current state of VR adoption is in COWI, and what should be emphasized in order to increase their VR capabilities in the future. Qualitative data is often used in intensive design and is better suited to analyze complex contexts (Busch, 2013). The epistemological stance of this research is interpretivism, whereas the ontological position is constructivism. Epistemological refers to the relationship between the authors and reality. The interpretivist approach means that the root causes found through observation in this study should not be regarded as absolute facts but as the perceived truth. Ontology refers to the nature of reality, and constructivism means that social reality is viewed to be influenced by social interactions and subject to change. Meaning that as interviewees share the same environment and interact with each other, their perception of reality is gradually aligned (Bryman, 2016).

3.1.1 Research process

The research process started with an initial literature review of VR in construction. This was done in order to gain insight into VR and VR adoption. Based on the literature review and discussions with a contact person in COWI, the research questions presented at chapter 1.2 were developed and refined. After refining RQ0, RQ1 and RQ2, the four key areas for VR implementation presented in chapter 2.4 were established through a second, more extensive, literature review. The key areas were then split into smaller sub-categories that enabled the authors to generate relevant questions, an overview of key areas and sub-categories that are shown in figure 9. Then the research design was refined and developed further allowing the authors to start the sampling of interviewees. A pool of relevant subjects for interview was made available through the contact person in COWI. The focus was on obtaining employees from different sections, at different levels in the organization and both from the Trondheim office and the Oslo office. After interviewees were selected the semi-structured interview guide was developed on the basis of gaining insight into all four key areas of adoption. Collecting and reviewing internal documents were done in parallel with conducting interviews in order to use the time between interviews efficiently. After conducting and transcribing 12 interviews and reviewing eight internal documents from COWI, five use cases and 18 observations regarding the current state of VR adoption were identified through coding. These were then discussed in light of existing literature that was regarded as relevant. For the 18 observations about the current state of VR adoption, causes and effects were discussed in relation to theory in order to develop suggestions for future improvements. Before concluding what use cases that are relevant for COWI, what the current state of adoption is, and what to improve, limitations, and new areas for further research were defined. The research process is illustrated in figure 7 below.

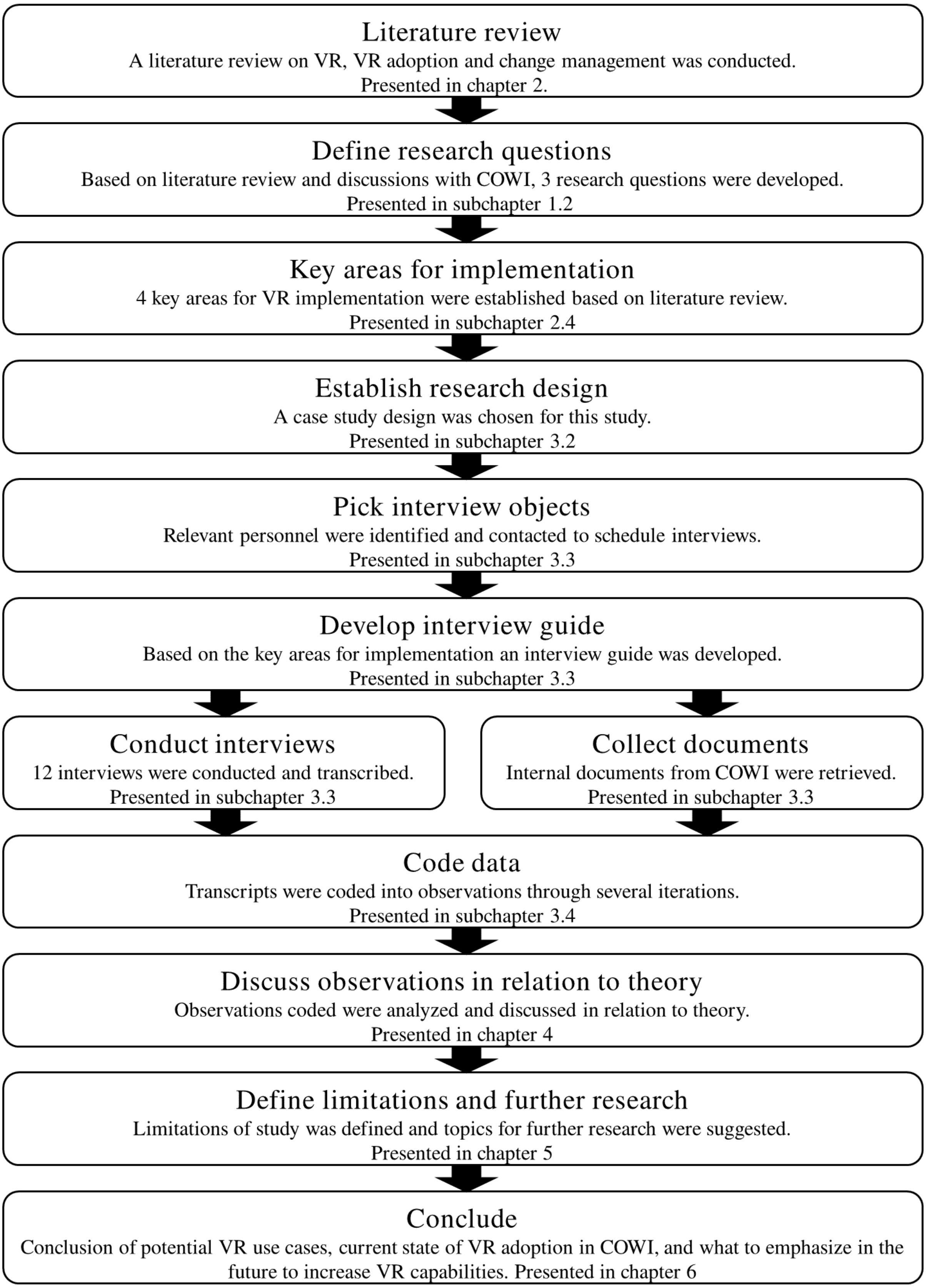

Figure 7: The research process.

3.1.2 Theoretical foundation

The scientific theory consists of literature that concerns VR in the construction industry, VR and technology adoption, and change management. In order to find literature relevant to the thesis, both keyword searches and reference searches were conducted. Academic databases chosen were Science Direct, Google Scholar, and Oria. They were picked for their high-quality reputation as well as offering a wide variety of articles regarding business and technology, making them well suited for this thesis. The databases also support AND/OR functionality, allowing keyword search to be more specific.

Sources used were sought to be as new and relevant as possible, and publishers like SAGE and Wiley are mainly sited due to their reputation as reliable, increasing the robustness of the theoretical foundation. However, the use of VR technology in construction is a field of study where little research exists and collecting reliable, relevant, and up-to-date information has been a challenge. In areas where academic databases lacked information, reports and whitepapers have functioned as a supplement. Internal documents from COWI has also been used to gain further insight into their VR capabilities.

3.2 Research design

The choice of research design is based on the purpose and the nature of the thesis. With the primary unit of analysis being employees in COWI, it was considered most suitable to conduct a case study. Bryman (2016) describes a case study as well suited for a qualitatively, intensive examination of an organization.

In this thesis, an intensive design is used. According to Busch (2013), an intensive design is characterized by exploring in-depth and utilizing relatively few sources where interviews are a common source. An intensive design shows its strength when a problem is complex with many variables (Busch, 2013) and this is the reason why it was chosen in this thesis.

The time respective in which the data is collected is essential. By collecting data at several different points in time, one can study complex time-dependent cause and effect relationships Busch (2013). In this thesis, the authors have chosen what is called a cross-sectional study. In a cross-sectional study, data is gathered at one point in time Busch (2013). Data collection for this thesis has stretched over a time period, but as each interviewee only has conducted one interview, it is to be regarded as a cross-sectional study Busch (2013). The reasons for choosing a cross-sectional study are the time limitation and the research questions aimed at identifying VR use cases for COWI, as well as diagnosing the as-is situation of VR and COWI and its potential for improvement.

3.3 Research method

This subchapter describes the selection of interview objects, how data was collected, and from which sources.

3.3.1 Interview objects

The goal of the interviews was to gain insight into how VR technology is utilized in COWI. Because of time limitations and the number of employees that could be interviewed, interviewees were purposively sampled. According to Bryman (2016), purposive sampling is when those sampled are strategically chosen based on relevance to the research question. It differs from probability sampling were picking of subjects is random. However, even though purposive sampling was utilized in order to maximize insight from a limited number of interviews, it is possible that the sample is to some extent, a convenience sample. Convenience sampling is when the sample is available by chance and not a strategic choice made by the researcher (Bryman, 2016). The interviewees were picked from a pool of relevant personnel that was recommended by the contact person in COWI. It is possible that particular employees were not made available as interviewees due to reasons beyond the authors' control, making the sampling partly based on convenience sampling.

Personnel with and without VR expertise in different departments and sectors were picked. This was done to enable a realistic and holistic view of COWI's VR capabilities. The purposeful sampling provided interviewees from different departments and roles, which were regarded as necessary for the analysis to be representative across the company.

3.3.2 Interview Guide

A general interview guide was created with questions covering each of the four key areas for VR implementation presented in chapter 2.4. The questions were formulated as open-ended to make sure that the relevant topics were covered without leading the respondent towards biased answers, and letting the interview flow as freely as possible within the area of interest.

According to (Yin, 2012), such semi-structured interviews can lead to richer and more extensive data than other methods and is well suited for use in case studies. The interview guide consisted of approximately 25 questions and was partly adapted to the interviewee's field of expertise in order to focus time used to areas were most insight could be gained. The guide was used as a loose framework during interviews, and as a reminder of which topics should be covered. In many cases, insights about the current VR situation in COWI were often gained through in-depth follow-up questions not included in the guide. The interview guide can be found in its completeness in Appendix 1.

3.3.3 Conducting interviews

As mentioned, the primary source of data for this study has been qualitative, semi-structured interviews. COWI employees were questioned about their thoughts and experience with VR technology within the four key areas of VR implementation presented in 2.4. Follow-up questions were asked as the interviewee highlighted different concerns within each area of interest. During the interviews, one author led the conversation, while one transcribed. The interview transcripts allowed for several examinations of the interview at later stages, increasing validity (Bryman, 2016). Due to the fact that interview lets the researchers gain first-hand information concerning the area of interest it is considered to be an essential source of data in a case study (Yin, 2014), making it well suited for this study.

In total, 12 interviews were conducted with personnel from the Oslo, Trondheim and Denmark office and across different sections. Eight of these interviews utilized the interview guide. Four additional interviews with VR experts were conducted (two of these were with experts from Denmark). These interviews all had a specific topic were insight about current VR initiatives in COWI and VR use cases were discussed in detail. The reason that two of the interviews were conducted with personnel from Denmark was to gain insight into a Norwegian-Danish research project currently being conducted. Due to the highly specific nature of these interviews, it was decided not to use the interview guide and instead use a list of questions regarding the specific topic of interest. During interviews the authors strived to uphold the two principles presented by Yin (2014), to follow a planned line of topics ensuring that the insights gained were of interest and to ask open non-leading questions in order to limit bias introduced by the interviewer.

Skype was used for conducting the interviews, which ranged from 30 to 60 minutes in length. It was highlighted that all interviews together would constitute the foundation for observations, and interviewees were anonymized. The interviews were also carried out with one person at a time. This was important in order to encourage the interviewee to speak freely. Table 2 presents an overview of the anonymous interviewees, were department, discipline, duration of the interview, and the number of words in the transcript is presented. For interview 1-8 the interview guide was used, interview 9-12 dealt with a specific topic of interest, and did not utilize the interview guide. In total, 16 580 words were transcribed over approximately 7,3 hours of interviewing.

Table 2: Information about interviewees. Shows the department the interviewees work at, what type of position they have, length of interview and words in the transcript. The number in column 1 correlates with the numbers behind each observation in figure 9 signalizing which interview corresponds with the observation.

Interviewee #	**Region**	**Discipline**	**Duration [min]**	**Number of words**
1	Oslo	Technical Director	30	1165
2	Oslo	RIV	38	1077
3	Oslo	LARK	47	1507
4	Oslo	BREEAM AP	46	1349
5	Oslo	RIE	37	988
6	Oslo	Project management	40	1619
7	Trondheim	RIB, BIM-coordinator	31	1091
8	Trondheim	RIE, BIM-coordinator	29	1715
9*	Oslo	VR specialist*	52	1854
10*	Denmark*	VR Specialist*	35	1659
11*	Denmark*	VR Specialist*	26	1243
12*	Oslo	VR Specialist*	27	1353
SUM	**N/A**	**N/A**	**438**	**16 580**

3.3.4 Other sources of information

In addition to the interviews conducted, documents were used as a secondary data source. Documents are considered a good source of data as they are stable, unobtrusive, specific, and broad (Yin, 2014). Internal documents from COWI include five PowerPoint presentations, one VR report, one survey, and one strategy report. These documents have given additional insight regarding the research questions as well as support findings from interviews. These documents are confidential and are subject of a non-disclosure agreement, and will therefore not be published. Information that is publicly available from COWI's web page, as well as news articles, has also been reviewed to provide context to the subject of this study.

3.4 Data analysis

This subchapter describes the overall strategy chosen for analysis, how the analysis is built up in two parts, and the coding process.

3.4.1 Analysis strategy

For this thesis, grounded theory has been the main strategy for analyzing the qualitative data collected through interviews and other internal documents. Bryman (2016) describes the grounded theory as well suited for investigating complex situations, making it suitable for an organizational study. In order to systemize and analyze the qualitative data gathered in this thesis, coding has been conducted. According to Bryman (2016), coding is the primary method in grounded theory and enables the researchers to systemize and analyze data through emerging concepts, categories, and potentially theories. In addition to coding transcripts, the researchers wrote notes and memos from the interviews in order to capture insight that did not come forth in the transcripts alone. The coding process is described in-depth in chapter 3.4.3.

3.4.2 Analysis part 1 vs. part 2

In order to answer the research question presented in chapter 1.2 in the best possible way, the analysis was split into two different parts. Part 1 is presented in chapter 4.1 and considers RQ0. This analysis presents and discusses insight gained from interviews and internal documents from COWI with existing literature regarding VR use cases in construction. This is a more simplistic analysis were the main goal has been to establish potential valuable VR use cases for COWI, and by that establish relevance for RQ1 and RQ2

Part 2 is presented in chapter 4.2 and considers RQ1 and RQ2. Here a more extensive analysis is conducted, with the goal of establishing what the state of VR adoption in COWI is, and what should be emphasized in the future in order to improve VR capabilities. Observations derived from coding are categorized and discussed in relation to theory in order to establish causes, effects, and suggestions.

3.4.3 Coding process

From the interview transcripts, line-by-line coding was done. (Strauss & Corbin, 1998) describe line-by-line coding as a very time-consuming method, but often a most generative method and therefore important at the beginning of a study. The process of coding was done in parallel with data collection in order to have the interviews fresh in mind when coding, as recommended by Bryman (2016). Each researcher did the first round of coding separately before the other researcher then reviewed codes created. This process was conducted to ensure that all information available was coded, as well as to align the researchers' understanding of the data gathered. The codes consisted of sentences rather than a word, which is commonly used in coding, to give more context. Originally too many observations were coded and they were later refined through two steps of refining as recommended by Bryman (2016). This process is illustrated in figure 8

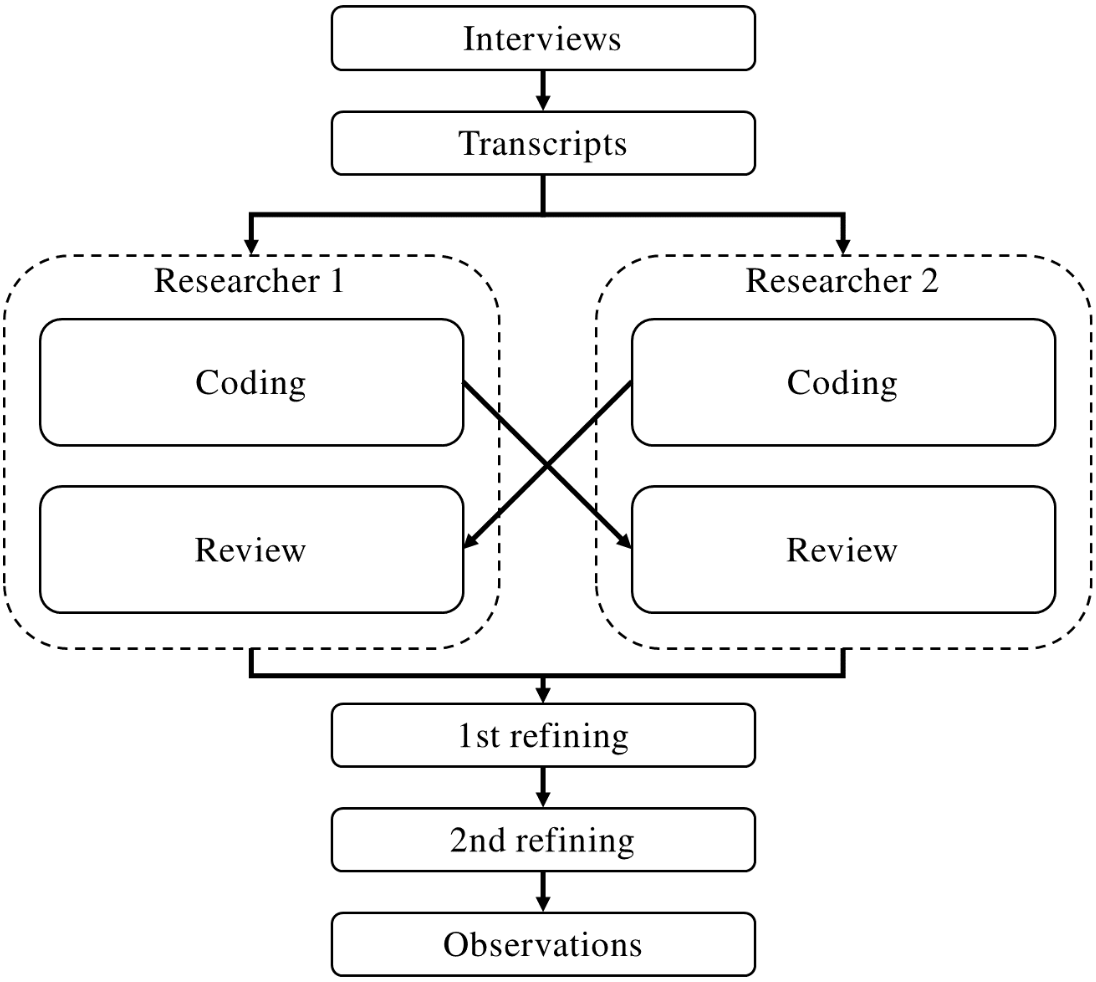

Figure 8: The coding process.

During the process of refining codes into observations, codes were crosschecked against transcripts in order to establish how many interviewees had expressed similar statements. Based on the number of interviewees that had expressed them and how relevant they were to the research question, the number of codes was refined from 72 to 18 as shown in table 3.

Table 3: Refinement of observations. Shows the steps of the refining process and the number of observations associated with each step.

Refinement of observations	
Number of initial observations	72
Observations after first refinement	51
Observations after second refinement	18

3.5 Quality of research

This subchapter discusses the quality of the research design that this thesis builds on. This is done by addressing the central research criteria for qualitative studies presented by Yin (2014): Reliability, construct validity, external validity, and internal validity.

3.5.1 Reliability

The reliability is meant to minimize errors and bias, by ensuring the conclusion is a reflection of the gathered opinions, and not the researchers' own beliefs. The reliability can be increased by demonstrating that other researchers can repeat the study and achieve the same results (Yin, 2014). In order to increase reliability, the authors strived to preserve a strong chain of evidence by several different measures.

During the start of the project, an online database was established and was used to store all data, literature, insight, and other resources gathered during the project. This ensured the safekeeping of data and easy accessibility for both researchers. Information was organized in folders in order to ensure a good overview, allowing researchers to easily find and review old interview transcripts, notes, or other resources. In addition, a digital protocol containing Gantt-charts, work-packages, interview dates, potential questions, and other notes were created in order to help the researchers always having a high-level overview of the project and data collection.

To further increase reliability, an interview guide was created and used during interviews. This guide is enclosed in appendix 1. Interviews were done through Skype, with one researcher conducting the interview while another writing a transcript. After an interview, researchers discussed the insight gathered in order to ensure that the qualitative data were understood in the same way.

In this study, data have been gathered from three sources: semi-structured interviews, internal documents, and publicly available information. Most data have been accumulated through semi-structured interviews, making it hard to repeat the research and gain the same data. This is because individual interview skills and cognitive limitations affect the interviews. Interviewees have also been anonymized, obstructing absolute repeatability and lowering the overall reliability of this study. However, as described in chapter 3.3.1 interviewees were purposely picked in order to ensure insight that is representative of COWI, increasing the chance of replicability if the sample criteria are met.

Regarding the internal documents retrieved from COWI, these are under the subject of a non-disclosure agreement and will not be published. In order for other researchers to gain access, COWI will have to make them available. Another aspect of the reliability of this study is time. Because COWI is an organization which is continuously changing, the reliability of this study may decrease with time. Due to a central part of this study is describing current VR adoption in COWI, a repeated study would not replicate the results, but describe the change in VR adoption over the time period between the two studies.

3.5.2 Construct validity

Yin (2014) describes construct validity as identifying the right operational measures for the concepts being studied. To ensure construct validity this study uses data from multiple sources like semi-structured interviews and internal documents from COWI. Having several data sources verifying the same fact increases construct validity. The authors have further strived to address construct validity by ensuring a strong chain of evidence through measures mentioned in chapter 3.4.1. Lastly, personnel from COWI have gone through a draft of the thesis, further increasing the construct validity.

3.5.3 External Validity

According to Yin (2014), external validity can be regarded as to which degree the findings can be generalized beyond the case study. This is generally a weakness in qualitative studies as a cause of small sample sizes (LeCompte & Goetz, 1982). This study goal is to assess VR use in COWI and does not investigate whether findings are applicable to other companies. However, it may be questioned whether or not 12 interviewees are adequate for attaining valid findings that represent the situation at COWI, especially for the Trondheim office where only two interviews were conducted. In order to increase the external validity, pattern matching and an extensive literature review were conducted as recommended by (Yin, 2014).

3.5.4 Internal validity

Internal validity relates to whether unknown casual relationships affect the conclusion of a study. According to Yin (2014), this mainly concerns exploratory case studies were the research question is “how” and “why” event X lead to event Y. In this study, several root causes to current barriers for VR adoption are identified. Whether or not these are actual causes or if the connections are casual is of importance. Internal validity is increased by matching the emerging patterns from analyzing the interview transcripts with the conceptual framework presented in 2.4. However, due to the qualitative nature of this study and the interpretivist approach used, the root causes found may not be the only truths, and should rather be understood as the authors’ perceived truths.

4. Results and discussion

In this chapter, findings from the interviews, data collection and literature review are presented. The findings are furtherly analyzed and discussed in the related chapters. Part 1 is the least extensive and forms the basis for Part 2, which is the main part of the analysis.

- Part 1: RQ0
- Part 2: RQ1 & RQ2

4.1 Part 1: RQ0

This subchapter presents the findings regarding research question 0.

- **RQ0: What are valuable use cases for VR in COWI?**

The subchapter is further divided into two new subchapters where the first address use cases identified from interviews and internal documents, and which are discussed in relation to relevant literature. The second elucidates insight gathered through the research regarding challenges and other considerations about the use of VR in the construction industry.

4.1.1 Use cases for COWI

For VR to be adopted in an organization, it must primarily show a relative advantage compared to the existing approach [2.1.3.1, para. 2]. In this subchapter, it is analyzed how various application possibilities can improve the work process in COWI. Most interviewees either had experience from, or an idea of, use cases of VR that could be valuable for COWI. The interviewees that were more adept in the use of VR technology often had more insight into valuable use cases. Additionally, an earlier study in COWI has researched VR use cases and their potential value, and has provided support for the results in this thesis. There were especially four areas of use that were frequently brought up [U1-U4]. Other use cases that were mentioned by fewer employees are included in U5. These use cases are further discussed in relation to theory in chapter U1-U5.

Table 4 summarize the findings regarding U1-U4 and their value. It lists identified use cases, their potential value, and relevant literature presented in chapter 2. The table is a visualization of the answer to RQ0.

Table 4: Overview of findings regarding potential VR use cases for COWI. The potential value is based on information gathered from COWI as well as existing theory in the field.

Use case	U1.1 Design review, with client	U1.2 Design review, in project team	U1.3 Design review, alone	U2 Simulations	U3 Marketing	U4 Sales
Potential Value	**Better projects** Improved quality and basis for decision making	**Better projects** Improved quality and basis for decision making	**Better projects** Improved quality and basis for decision making	**Better projects** Improved quality and basis for decision making	**COWI marketing** Improve COWIs reputation for digital excellence.	**Increased sales** Competitive advantage in tenders.
	Fewer mistakes Better detection of clashes and potential errors.	**Fewer mistakes** Better detection of clashes and potential errors.	**Fewer mistakes** Better detection of clashes and potential errors.	**Cheaper projects** Decreased risk of budget overruns.	**Client marketing** Opportuinty for providng extra services.	
	Time savings Faster completion, increased accuracy.	**Time savings** Faster completion, increased accuracy.	**Time savings** Faster completion, increased accuracy.	**Time savings** Faster completion, increased accuracy.		
	Cheaper projects Decreased risk of budget overruns.	**Cheaper projects** Decreased risk of budget overruns.	**Cheaper projects** Decreased risk of budget overruns.	**Faster adoption** Client can start using building sooner		
	Increased ownership Managing client expectation.					
Relevant literature	Chapter: 2.3.1.1, 2.3.2	Chapter: 2.3.1.2, 2.3.2	Chapter: 2.3.2	Chapter: 2.3.1.3, 2.3.2	Chapter: 2.3.1.4	Chapter: 2.3.1.5

U1 Use case 1: Design review

Design review and design optimization is a central process amongst personnel in COWI and using VR for this purpose can be seen as a way of improving internal efficiency [2.1.1, para 2]. Reviewing the model through VR tools can give the user a better overall spatial understanding than with a regular desktop 3D model [2.3.2, para. 2]. This can possibly enable a better understanding of how well the building fits the end-users needs, lower ambiguity in the project group and inspire more feedback from users during the design phase [2.3.1]. When talking to COWI employees three different types of design review were suggested, namely design review ”with client”, ”in project team” and ”alone”.

U1.1 With client

The most mentioned use case for VR by employees was “design review with the client.” The client is often not familiar with working in technical models and often struggles to understand what a 3D modelled room will be like in real life [2.3.1]. VR allows the client to “test” the building at an early stage in the project when changes are still not too expensive to make. COWI has done this in several projects, and employees have stated that by showing the model in VR, more enthusiasm is created as well as more feedback from the client than through regular 3D models. By getting more feedback at an early stage, the design can be optimized towards the client needs, increasing the quality of the building/project [2.3.1]. Because clients might have difficulties in understanding 3D models there might exist ambiguity between the project group and the client. This ambiguity may lead to misunderstandings. By lowering ambiguity and managing client expectations through VR, one can ensure better communication and understanding between COWI and the client. This increased transparency can potentially lower the possibility of a costly and time-consuming legal dispute, which affects many construction projects. In addition, the client will have a feeling of increased ownership due to becoming more involved in the design processes and decisions.

U1.2 In project team

Several interviewees expressed that the use of VR for cross-disciplinary meetings could be valuable for COWI. Several potential benefits were presented. By having walkthroughs in VR, initial ambiguity in the project team surrounding design could be lowered, and decision basis strengthened. It could also be used for collision control across disciplines. This can lead to fewer mistakes and reduce the risk of budget and schedule overruns in the project [2.3.1]. In addition, by using 4D BIM the sequences of installation as well as planning of space on the construction site could be optimized and time used during construction could be reduced [2.3.1]. Some employees were uncertain about the value of this use case. They argued that visualization in regular BIM could be sufficient, and the value of using VR in cross-disciplinary meetings depends on the participant's ability to understand a model with or without using VR.

U1.3 Alone

Another use case that was suggested by COW-employees is using VR for personal walkthrough of the 3D-model. Some of the interviewees did this on a regular basis and found it to be valuable for them. While working with a model in for instance Revit (BIM), the model can easily be transferred to VR with the possibility of observing what has been designed in a more nuanced perspective [2.3.1]. When using VR, it is easier to check how the visibility, accessibility, and spatial feeling is in a room than it is in a regular 3D model [2.3.2, para. 2]. It is also possible to change the VR view to the viewpoint of a specific group of users, e.g. children or wheelchair users, in order to see the room from their perspective. Interviewees expressed that this can lead to increased quality of design and lower the risk of design errors, potentially cutting cost and time. However, it was argued by employees who were not familiar with the use of VR that this process seem time-consuming and that they would rather review the model through regular BIM.

U2 Use case 2: Simulation/Training

Employees stated that a valuable use case is using VR to simulate dynamic operations in a 3D model. This is done in order to test how a design supports or hinders day-to-day operations as well as emergencies. This can be seen as a way of improving internal efficiencies, as optimization of design is a much applied process in COWI [2.1.1, para 2]. When conducting large projects like hospitals, optimizing the building towards usability is very important. Current methods of simulating how an end-user will use the building involve the use of physical mock-ups. Building these mock-ups can be costly and time-consuming. By utilizing VR, both time and cost of simulation can be cut, allowing for more iterations and resulting in a better quality build at the end [2.3.1]. An external opportunity that was brought up by employees is using VR to familiarize a building layout for an end-user before they move into a building [2.1.1, para. 3]. This is especially important for hospitals, as personnel needs to know the building well before patients can move in. Having personnel familiar with using the new hospital before finishing construction can lower the time needed for adaption to the new building and in turn, reduce the overall cost for the client.

U3 Use case 3: Marketing

Employees expressed that one of most applied use cases of VR in COWI is using it as a tool for marketing. When having stands at conventions where current and earlier projects are displayed, visitors can walk around in a 3D model either using a phone and cardboard glasses, using HMD, or entering a VR cave. Even though VR has existed for many years, widespread VR use in the construction industry is somewhat new, and interviewees stated that it has a "wow" effect, which correlates well the literature review [2.3.1]. By using VR as a way of drawing attention to COWI and COWI projects, VR is a way of improving the internal efficiency of marketing [2.1.1, para. 2]. There is also an external opportunity regarding VR as a tool for marketing [2.1.1, para. 3]. By selling a VR-model as part of a delivery to clients, the client can use the VR model as marketing towards their own customers. This can especially be valuable for a clients who are renting out space in finished buildings or projects [2.3.1].

U4 Use case 4: Sales

Several employees highlighted the value of using VR as a tool for winning tenders. Some respondents expressed that this can provide a competitive advantage because of the high novelty value of VR. They believed, however, that the novelty value would eventually drop, and that VR would be an expected service towards clients in the future. While VR still has novelty value, it represents an external opportunity where VR can be offered in delivery as an extra service towards the client, separating COWI from competitors [2.1.1, para. 3]. In addition to being an extra service towards a client, it helps to display excellent technical competence, further building COWI's image as a market leader within technology in the construction industry [2.3.1].

U5 Use case 5: Other suggestions from employees

In addition to the four aforementioned use cases that were repeatedly brought up by interviewees, there are some other use cases which were mentioned by fewer employees. One suggestion was using VR as a communication tool for project meetings in favor of skype. Another one was adding acoustics to the VR model when running design reviews to enable more coherent understandings of what planned design will sound like. Due to a limited scope, the authors decided to focus on the most mentioned use cases [U1-4].

4.1.2 Considerations

The previous subchapter displays the benefits of using VR for various use cases. This subchapter address complications and considerations related to the adoption of VR.

First of all, there are various costs involved that must be considered. Initially, implementing VR requires investments in hardware and software. These are relatively small investments in the context of construction projects, but in an industry with many competing suppliers, there is often a very tight budget, and all investments must be accounted for. Additionally, using VR in projects requires the time of the personnel involved in the process. This applies both to the personnel preparing the use of VR, and the personnel that is involved in using VR in project meetings, etc. However, VR has become a technology of relatively low user complexity in the context of construction projects, which has a positive effect on the ability of personnel to be efficient in adopting new work habits [2.1.3.1, para. 3].

For VR to be worth implementing, these costs will have to be reimbursed by the benefits gained in some way. Many claim that the benefits often outweigh the costs significantly, but that the problem is that benefits gained are primarily in the form of intangible and unmeasurable assets [2.3.2, para. 1]. The perceived benefit of VR is through improved visualization, which in turn should lead to a better understanding of models, improved ability to identify problems, etc. This should eventually lead to value, e.g., in the form of constructions that are more aligned with the expectations of the customer, inducing fewer issues with change requests, more satisfied clients and an improved reputation for COWI. The problem here is that all the mentioned effects are very challenging to measure because there are so many factors influencing these results. For instance, it might be difficult to decide whether an error would be identified at a later stage if it had not been discovered in VR.

Additionally, the value of using VR in projects is not universal. It will vary depending on the type of project, the complexity, stakeholders and personnel involved, etc. Therefore, it is necessary to find alternative ways for determining the value of using VR in different kinds of projects for COWI.

Another important aspect of the use of VR is that its value must be seen in comparison to other media of visualization. The original visualization media is using computer screens for displaying the 3D-model. This method will continue to be the most effective visualization tool in many areas because of the availability, and the high ability to interact with the model. VR must be understood as a supplement to traditional screen-BIM and not a replacement.

4.2 Part 2: RQ1 & RQ2

In this part of the analysis, the findings regarding research questions 1 and 2 are presented, analyzed, and discussed.

- **RQ1: What is the current state of VR adoption in COWI?**
- **RQ2: What should be emphasized in order to increase COWI's VR capabilities?**

Research question 1 is answered by measuring data gathered from interviews towards the framework for implementation of VR, which was identified through the literature review [chapter 2.4]. This framework sections VR implementation into four key areas of examination, these are categorized from K1 to K4 as illustrated in figure 9. In order to ensure that interview questions covered the key areas extensively, these key areas are further divided into more defined subcategories by the authors, to which observations are connected. To ensure verifiability, observations are listed with numbers referring to which interviewees have expressed this statement. The corresponding numbers can be found in table 2. Each observation is independently discussed and jointly compris the answer for research question 1.

Furthermore, the observations are analyzed in relation to theory to be able to uncover the causes of existing problems. Ultimately, five major root causes are identified. These are noted R1- R5 and are listed together with each corresponding observation. Causes are further discussed with respect to existing theory in the field, finally providing the foundation required to offer suggestions for future work needed to enhance VR capabilities. These suggestions constitute the answer to research question 2. For some observations, causes or suggestions are not presented due to being regarded as irrelevant by the authors.

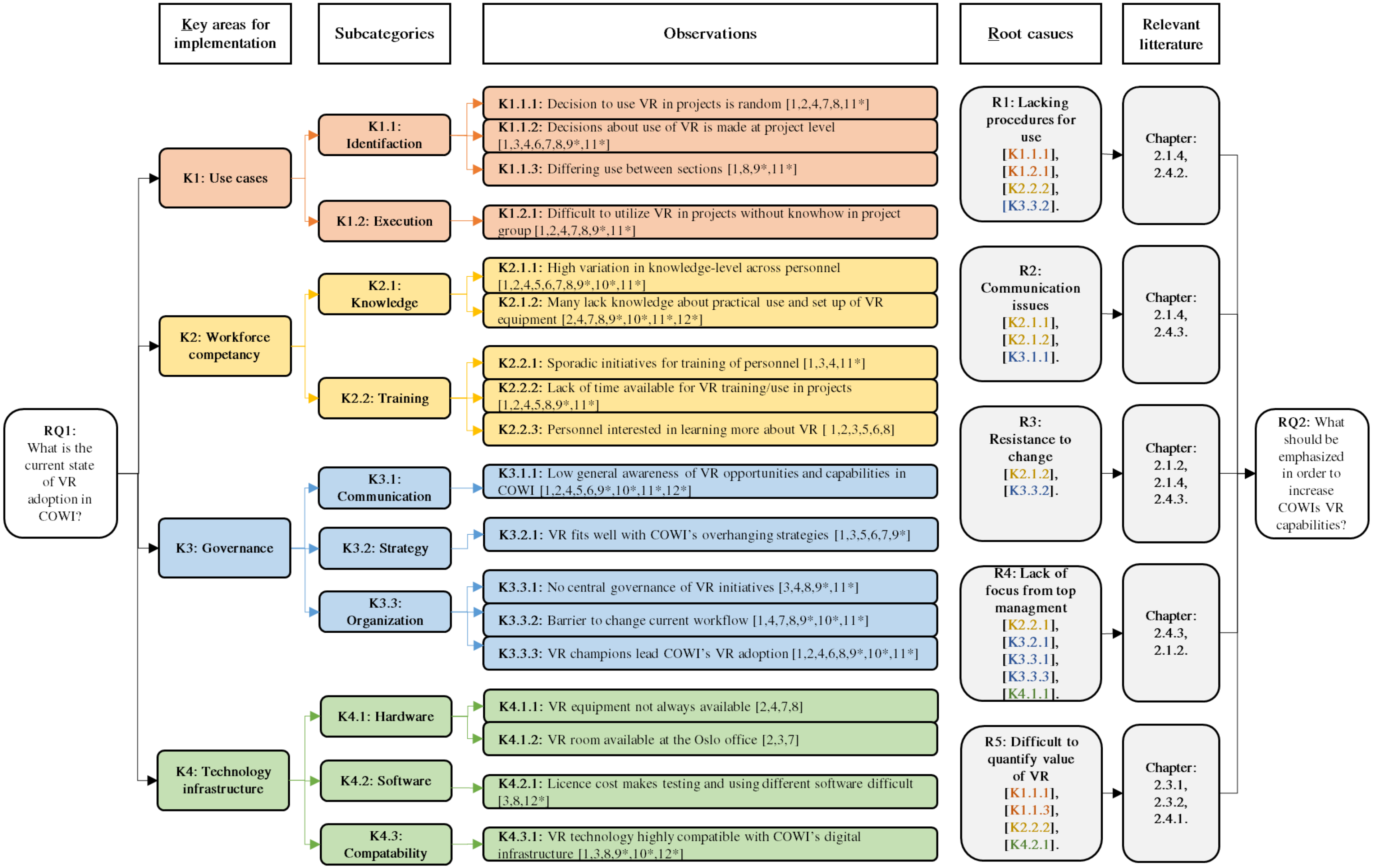

Figure 9: Framework and observations regarding current state of VR adoption in COWI.

K1 Use cases

In this subchapter, observations about how COWI identifies use cases and utilize VR in projects will be presented and discussed. It is divided into two subcategories:

- K1.1 Identification
- K1.2 Execution

K1.1 Identification

To be able to acquire the potential benefits of VR technology it is first necessary to identify the correct use cases for the various areas of application. For COWI, who mainly create value through projects, this means two things. Firstly, it is the need to identify which processes that can be improved through the use of VR. These findings are presented in chapter 4.1. Secondly, there is the need to identify which projects should utilize VR and in what way, which is addressed in this subchapter. During interviews the following observations regarding identification of use cases were done:

K1.1.1 Decision to use VR in projects is random

Explanation:
Interviewees expressed that the decision to make use of VR in projects, as well as the choice of use case applied, is often random and depending on personal interests rather than on project need or potential business value. It was identified that most personnel have some idea about possible use cases, but that the information is usually scarce and not up to date. On the other side, there are enthusiastic VR Champions that are eager to try out VR technology. Moreover, employees describe a lack of plan behind the use of VR in projects.

Causes:
As described in detail in chapter 4.1.2, it is difficult to measure the benefits gained by using VR in the various use cases [R5]. This leads to low observability of VR [2.1.3.1, para. 5] and hampers employees' ability to identify which use cases are valuable in which projects.

Furthermore, the decision to use VR is made in projects [K1.1.2] which means that it is up to the personnel in the project team to choose whether VR will be used for other than use case U1.3 (Design review alone). Since procedures for when and how to use VR has not been established in COWI [R1], this decision depends on the knowledge and interest of individuals in the project team rather than on organizational knowledge [2.4.2, para. 3]. There is generally low awareness of VR in COWI [K3.1.1], and highly differing knowledge [K2.1.1]. If the team lacks personnel who are interested in VR, it is highly likely that VR will not be considered at all. This is further described in observation K1.2.1.

Effects:

Making uninformed decisions regarding when and how to use VR can lead to disadvantages for example by not utilizing VR in a project where one could gain value from one or several use cases. Another example is utilizing VR without considering what one is trying to achieve. Without clear goals for the use of VR in a project, achieving and measuring the success of use becomes difficult. Furthermore, improper usage of VR can cause additional work for personnel involved, and lead to a lessened perceived value amongst participants. This can, in turn, decrease the adoption rate of VR [2.1.3.2, para. 2].

Suggestions:

To be able to make informed decisions about how VR should be applied in a given project it is necessary for relevant personnel to understand the value of the use cases. Because of the challenge in quantifying the value of VR, it is suggested that more qualitative approaches should be used to acquire knowledge about the value of using VR for various applications. It is recommended that a system is established for gathering insights gained from previous projects about the benefits and challenges faced with use of VR. This should be done by a designated unit responsible for organizing double-loop learning, with a focus on continuously evaluating not only the effectiveness of the implementation of VR, but also assessing the goals behind the application in relation to the results [2.4.2, para. 4]. It is important, for instance, that the goal of achieving better visualization is assessed in relation to the risk involved with the final construction design. Also, new benefits and competitive advantages can arise when applying new technology of this kind, something which should be considered when evaluating performance. Organizing feedback loops for experience gained from VR will subsequently enable COWI personnel to make informed contributions when VR is being considered applied in a project.

Another aspect of empowering personnel to make informed decisions is that awareness of the VR possibilities available is created within COWI. This can be achieved both by improving internal communication (elaborated in detail in K3.1.1), and by establishing procedures that facilitates a more informed decision process in projects (elaborated in K1.2.1).

K1.1.2 Decision about use of VR is made at project level

Explanation:

It was observed that the decision whether to use VR extensively or not is made decentralized in each separate project. This decision is often done in collaboration with the client who requests it or COWI personnel who suggests it, and it becomes a part of the delivery. However, on a lower level, all personnel in COWI can use VR equipment as they see fit in order to conduct their work [U1.3]. Some interviewees had used VR out of self-interest to improve their workflow, without having VR as a stated delivery in their project.

Causes:

Currently, the use of VR is seen as an extra service that COWI is able to deliver to a customer and not a mainstream digital tool for conducting construction projects. Because all projects have clients with different needs, it is therefore natural that the decision to utilize VR is taken in the project group. This is functional as the project team often has a better knowledge about project needs than upper management [2.4.3, para 3]. It is also likely that it is partly because the adoption of VR technology is a bottom-up initiative in COWI [2.1.2.1 & 2.4.3, para 3].

Effects:

If decisions are made in the project team, it relies on the knowledge of use cases of VR technology that the project group has. As observation K2.1.1 states, the knowledge level across personnel is not consistent, and in combination leads this to the use of VR being random [K1.1.1], differing use across sections [K1.1.3] and that it is challenging to use VR without know-how in the project group [K1.2.1].

K1.1.3 Differing use between sections

Explanation:

Interviewees expressed that there are some differences between sections within COWI. It was especially mentioned that Landscape and Infrastructure had come further in utilizing VR technology than other sections.

Causes:

Due to VR usage being led by VR Champions [K3.3.3], and the highly differing knowledge-level across personnel [K2.1.1] it is likely that differences across sections are due to differences in employees' interests rather than differences between the sections themselves. Because of a lack of centralized governance [K3.3.1], the spreading of information and knowledge about VR is solely based on VR Champions. In sections where VR Champions are more active, it is likely that VR adoption has come further [2.4.3, para. 4].

There were however one hypothesis expressed as to why Landscape and Infrastructure had seemingly come further than other sections. The reason mentioned was that they had been able to identify design review [U1] and simulation of roads [U2] as valuable use cases. Having identified valuable use cases and communicating this seemingly aid employees in discovering the meaning of the changes, leading to more adaptive attitudes and behavior [2.1.2.2]. It also makes it easier to communicate value and to increase perceived usefulness [2.1.3.2, para. 2]. Lastly, it makes it easier to make an informed decision about when to use VR and for what, and in turn, increasing the adoption rate of VR [2.4.1]. It can, however, be challenging to define valuable use cases, as it is hard to quantify the value of VR use in construction [R5].

Effects:

By having differing VR use across sections, it is possible that this will lead to increased differences in knowledge level across COWI [K2.1.1]. Sections with more use of VR will likely learn more, whereas sections with little use will likely develop little new knowledge.

Suggestions:

To be able to systematically transfer knowledge from sections that have come further in adopting VR, a centralized unit for governance of VR should be established where knowledge gained across sections can be stored and redistributed [2.4.3, para. 3]. This is elaborated further in K3.3.1. Additionally, which potential use cases that are valuable for which sections of COWI should be mapped [2.4.1].

K1.2 Execution

After identifying the right VR use cases for a project, the actual use of VR begins. Adopting new technology and utilizing it is difficult since it requires some degree of organizational change, and companies often struggle using the technology efficiently in order to get maximum value from it [2.1.2]. Through interviews following observation regarding the execution of VR technology in projects were made:

K1.2.1 Difficult to utilize VR in projects without know-how in the project group

Explanation:

Interviewees expressed that without VR skilled personnel in the project group utilizing VR in the project became difficult. Therefore, having VR skilled personnel in the project team is essential for the adoption of VR in COWI [2.4.2, para. 1].

Causes:

Since the decision to use VR is made by the project team in each individual project [K1.1.2] the know-how and interest in VR by personnel in the project team are critical. If no one in the project group brings up the possibility of using VR, it will not be used extensively in the project.

In addition to this there are many who lack knowledge of the practical usage and set up of VR equipment [K2.1.2]. Lacking time for training [K2.2.2], combined with lacking procedures for use [R1] makes utilization of VR difficult in projects without the know-how within the project group.

Effects:

The difficulty of utilizing VR in a project without former know-how increases the barrier to change current workflow [K3.3.2] and hinders the use of VR in projects, which makes widespread adoption of VR technology harder.

Suggestions:

To lessen difficulties with using VR in projects without know-how in the project team, the suggestion is to develop exhaustive VR procedures which are to be made available on the VR Community site in the COWI portal. There should be both guidance for identifying the correct use case and way of application in projects, as well as step-by-step guides for implementing the different types of use cases [2.4.2, para. 3]. Furthermore, it is imperative that these are designed to be understood by personnel with no prior VR experience. This is a measure that requires little effort compared to the substantial and lasting reward that can be retrieved. Another measure for facilitating more use of VR is by increasing knowledge about VR in COWI, which is discussed in-depth in K2.1.2.

K1 Summary

Insight gathered from interviews about use cases in COWI shows that the decision of whether VR is used or not is taken at project level [K1.1.2]. As of now, there exist no official procedures or routines for identifying which use cases are relevant and how VR should be used in practice [R1]. The use of VR is therefore highly dependent on the knowledge contained by the project team in each separate project [K1.2.1]. In combination with the highly varying knowledge level [K2.1.1] and low general awareness about VR across COWI [K3.1.1], it leads to VR use in COWI being random [K1.1.1] and not based on the needs of the project. In order to optimize value from use, and attain commitment for adoption of VR, it is vital that the right use cases are identified. In addition, COWI should consider developing procedures and guidance for VR use which should be readily available in the VR Community in order to increase ease of use [2.1.3.2, para. 2] and in turn, increase COWI's VR capabilities [2.4.2, para. 3].

Some of the issues regarding the use and adoption of VR in construction are likely due to the fact that value gained from using VR is difficult to quantify [R5]. Traditional cost-benefit analyses are not as applicable for assessing VR use in construction, as benefits gained are often intangible [2.3.2, para. 1]. Internal differences observed across sections in COWI emphasize this issue [K1.1.3]. Sections where valuable use cases of VR had been established and communicated had come further in adopting VR technology. This may stem from a higher perceived usefulness and adaptive behavior, which in turn breeds higher adoption rate [2.1.2.2 & 2.1.3.2, para. 2]. This leads the authors to argue that establishing valuable use cases and communicating this across the organization should be a high priority when it comes to VR adoption in COWI [2.4.1].

To be able to enable informed decisions of when to use VR it is recommended that a system is developed for recording insights and best practices discovered in projects using VR in COWI. By having a designated unit responsible for facilitating double-loop learning [2.4.2, para. 4], it is possible to store and act on experiences gathered gained from projects. Additionally, to be able to measure the successfulness of VR in a project, clear and measurable use cases should be defined in each project, eventually making it easier to evaluate the result of the usage.

K2 Workforce competency

This subchapter covers the observations about VR competency in COWI. It is divided into two areas:

- K2.1 Knowledge
- K2.1 Training

K2.1 Knowledge

To be able to utilize the benefits of VR, it is important that relevant personnel have the necessary know-how about VR. Having personnel with the right knowledge has been seen as a vital factor for early adopters in other industries [2.4.2, para. 1]. This includes knowledge about the benefit and potential of VR, as well as technical knowledge about software, hardware, and using VR tools. Through interviews following observation regarding knowledge about VR were made:

K2.1.1 High variation in knowledge-level across personnel

Explanation:
The knowledge about VR varies a lot amongst the employees in COWI. There are a number of VR Champions across the different departments of COWI. They have taken the initiative to learn about VR out of personal interest. They possess extensive knowledge about the different application possibilities of VR as well as knowing how to proceed in order to implement VR in projects. VR Champions are listed in the VR Community site of the COWI portal. There are eight official champions in the Oslo office, five in Trondheim and 43 in total within the organization. However, when looking at the non-VR Champions of the organization, the average VR knowledge level is relatively low. The majority of personnel in the departments investigated in this study do not have thorough knowledge about the use or the potential of VR. This finding is also consistent with the results from the 2017 COWI Try Questionnaire where 50 out of 64 COWI employees questioned had never used VR in a project.

There were some uncertainty and misunderstandings to be observed regarding "who knows what" about VR among general personnel, indicating that most employees do not have a good understanding of what VR competence COWI inhabits.

Causes:

The main reason for varying VR competency is that use and development are based on personal initiatives [K3.3.3]. There is no established central governance unit, which may help ensure that VR knowledge is spread and general VR competency is increased [K3.3.1]. There are sporadic efforts from VR Champions in educating personnel [K2.2.1], but these never reach the majority of employees. This can further be traced to the cause that communication about VR does not reach a broad audience [R2].

Effects:

Varying competency is not a negative observation in itself. The competence required will depend on the role and responsibilities of the person. However, the high fraction of personnel that is not knowledgeable in VR leads to barriers to successful implementation [2.4.2, para. 1]. First and foremost, it is a distinction between the need for knowledge about practical use and set up of equipment and software, and knowledge/awareness about the different use cases of VR and its value. To be able to cover this topic exhaustively, lacking knowledge is further elaborated in their corresponding discussions of observations, respectively K2.1.2 and K3.1.1. This variation in knowledge contributes to the randomness of VR use [K1.1.1].

When it comes to the competent VR Champions, this presents an excellent opportunity for COWI. They account for much of the reason why COWI has started to adopt VR today. Their competence is a resource that will be crucial for the implementation of VR in COWI [2.4.3, para. 4].

Suggestions:

In order to be equipped for making the right choice when deciding which projects should use VR, the competence must be spread across the different departments and disciplines [2.4.2, para.3]. Suggestions regarding lack of knowledge about the practical use of VR are further described in K2.1.2 while suggestions regarding lack of awareness of VR opportunities are addressed in K3.1.1.

When it comes to the competence available amongst VR Champions this can be purposely applied to perform effective internal educating of personnel in the different departments [2.4.3, para. 4]. Additionally, there are opportunities to use competent personnel directly as a resource for consulting in specific projects or when counselling is needed.

In order to get an overview of potential lack of knowledge, it might be in COWI's interest to map knowledge currently existing within the company, as this seems to be somewhat fuzzy among interviewees.

K2.1.2: Many lack knowledge about practical use and set up of VR equipment

Explanation:

The observations identified that one barrier restricting the use of VR is the lack of knowledge about how to set up VR equipment and how to use the equipment. Not everyone will need to know how to set up the equipment, as this can be done by certain competent personnel in the department. However, to enable efficient work and a low threshold for use, there is a need for more widespread fundamental knowledge about the practical use of VR [2.4.2, para. 1].

Depending on the type of VR and degree of immersion, setting up VR equipment usually involves:

- Obtaining the necessary equipment
- Connecting and preparing equipment
- Obtaining and enabling software license

With equipment installed, the main elements of practical use involve:

- Converting the BIM model to VR
- Operating the VR model

Causes:

One cause for lack of knowledge about the practical use of VR is low awareness about the opportunities that exist [K3.1.1], which is an effect of communication not reaching a broad audience [R2].

Another reason is that, even if people are aware of the possibilities, there is a lack of time available for learning about VR. This is further elaborated in observation K2.2.2.

A third explanation is that personnel consciously choose not to spend time on VR because they believe it is not valuable to them. However, according to observations, most personnel believe that the use of VR would be valuable in projects. This is backed up by the COWI Try questionnaire from 2017, where the majority of respondents think VR would improve the way they work. This cause, therefore, appears to apply only to a minority of the personnel.

Effects:

The initial effect of the lacking knowledge of how to set up VR equipment is that it becomes a barrier for facilitating VR use in projects. The lack of knowledge of practical use furtherly creates a barrier for low-level usage of VR.

Secondarily, the lack of information in itself can lead to a misconception about the amount of work needed to make use of VR. This is especially relevant for innovations such as VR because rapid improvements in technology often lead to performance improvements without the general public being aware. As elucidated in the Technology Acceptance Model [2.1.3.2, para. 2], the user's "perceived ease of use" is a main decisive factor for the attitude towards use, which will furtherly affect the employee's intention to use VR. Lacking information about the comprehensiveness of use can thus lead to barriers for personal use, as well as making it less likely to include VR as a part of the project delivery in project meetings [K3.3.2].

Suggestions:

The natural response to a lack of knowledge is to facilitate the upskilling of personnel, which can be approached in different ways. One way is to initiate internal VR training for COWI personnel [2.4.2, para. 3]. This can for instance be done by assigning competent VR Champions to hold courses during an "educational lunch," or by systematically sending the most relevant personnel in different departments on training sessions. The interviews show that 6 out of 8 respondents questioned explicitly expressed their wish to learn using VR by learning from someone who is good at it.

2 out of 8 respondents would prefer to learn using VR by self-study. For several of the tasks needed for the use of VR, there is guidance available on the VR Community site in the COWI-portal. The "Borrow VR kit" section presents a list of what equipment is available for use in the different departments, along with a short description, price range and whom to contact in order to obtain it [Appendix 2]. In the "VR Guides" section, there are guides on how to convert a model from Revit to VR and creating and viewing 360-degree panorama images. The benefit in learning by self-study is that it does not require the time or planning required by involving other personnel. However, as this is very practical work, it might lead to extra work by more trial and error. Additionally, this type of learning from guidelines and written instructions is

categorically explicit knowledge, and it does not cover the tacit knowledge that is an essential part of the VR practice [2.4.2, para. 5].

The best solution is probably applying a combination of the two aforementioned approaches. The VR Community site represents a bank of knowledge that can be utilized as an economic and low-threshold service. However, as of today, it does not cover all aspects needed for independently making use of VR. By developing the VR Community further, with procedures as elaborated in K1.2.1, it is possible to obtain higher VR possibilities without significant additional costs.

An alternative response to the lack of knowledge on how to set up the VR equipment is to reduce the need for it by establishing more VR-rooms in the different departments. Challenges regarding this are elaborated in K4.1.2.

K2.2 Training

As illustrated in the previous paragraph, upskilling is integral in acquiring the required competence. Other solutions, such as outsourcing tasks or hiring experts, are considered subordinate in this context due to the internal competence latently available in COWI. This subchapter addresses the observations made of current VR training:

K2.2.1 Sporadic initiatives for training of personnel

Explanation:

The only type of upskilling of personnel observed through semi-structured and supplementary interviews are individual initiatives from VR Champions. This includes initiatives to offer training on request, VR Community meetings as well as a "Roadshow presentation" in association with a VR research project (further described in K3.3.3), spreading awareness about VR opportunities and use cases. Much of the information observed through the interviews originates from this presentation, which displays the significance of this initiative. However, interviewees expressed that presentations like these were rare and that knowledge gained from them faded fast due to lack of repetition and little actual use in projects.

Cause:

The cause of these upskilling initiatives is that champions are leading the development of VR [K3.3.3]. The reason these efforts are sporadic and not systematic can be rooted in a lack of focus from top management [R4].

Effect:

These upskilling initiatives are the reason VR competence is not entirely deficient in COWI. However, with the upskilling of personnel limited to sporadic initiatives, the competence diffusion will be somewhat arbitrary. This inconsistency in the upskilling can, in turn, lead to an unbalanced distribution of VR competency and a lack of VR knowledge amongst personnel that could indeed benefit from higher competence [K2.1.2].

Suggestions:

To be able to achieve a fundamental level of awareness amongst employees, measures like this will have to be implemented in a structured manner across the different departments [2.4.2, para. 3]. As training requires time, it is likely that management needs to take a more active role in the training of personnel, in order to allocate necessary time and resources.

K2.2.2 Lack of time available for VR training/use in projects

Explanation:

The observations show that a cause of deficient knowledge about VR is time pressure. Most respondents experience that their workloads are already heavy and that finding the time to learn about VR is not prioritized.

Causes:

When working in a consulting firm, it is desirable to fit as many working hours as possible into projects in order to maximize profitability. Thus, if time is not designated for working with VR in projects, hours spend on upskilling either have to be paid for by COWI or done during the spare time of employees. A barrier for justifying the hours spent on VR in COWI or projects is the inability to quantify the value the use of VR can bring [R5].

So far, a significant part of the VR competency has been rooted in initiatives from individuals. As discussed in K2.1.1, COWI should not rely entirely on the initiatives of individuals to achieve satisfactory implementation across the organization. Causes for lack of time available for training is therefore lacking measures for performing upskilling in COWI, and that it is not a part of project deliveries. This can further be rooted in a lack of focus from top management [2.4.2, para. 1-3] [R4].

Due to the fact that there are no procedures or guidelines for VR use [R1], employees who want to utilize VR have to use additional time finding the right use cases and learning how to use VR equipment through external sources. This increases the time needed for training/use of VR in projects, making it even more challenging to utilize VR in projects with time limitations.

Effects:

Lacking time available for upskilling results in personnel not acquiring the competence in VR that they want or need [K2.1.2]. It will cause a reduced trialability [2.1.3.1, para. 4] that can result in an inability to see valuable use cases or to see the amount of work needed for satisfactory use. These two factors jointly determine whether technology is utilized or not [2.1.3.2, para. 2], and are therefore decisive for enabling VR to be used in projects where this would be beneficial. By not allowing for enough time for training/use of VR, it becomes harder to change current workflow [K3.3.2], further limiting adoption rate.

Suggestions:

One way to approach this issue is for COWI to specifically set aside time for certain personnel to train or attend courses in VR as elaborated in K2.1.2.

Another approach is to work towards letting VR become more included as a part of project deliveries by pitching it in projects. This way, personnel will have the opportunity to gain VR knowledge by applying it directly in projects which can be useful as well as an economical learning method. However, this requires some fundamental awareness about use cases and value amongst someone in the project to make sure it is implemented in the right way [K3.1.1].

K2.2.3 Personnel interested in learning more about VR

Explanation:

A recurring observation is that respondents expressed interest in learning more about VR.

Causes:

This interest may stem from the belief that VR in some way may be useful in their work, but it can also be rooted in fascination for unfamiliar technology.

Effects:

Interest is central in determining how effectively people process information [2.4.2, para. 2], and this observation displays the opportunity to effectively upskilling motivated personnel in VR. Working with something considered interesting also benefits personal motivation and can have positive effects on morale in the workplace. This can eventually lead to reduced barriers to change current workflow, and thereby increased possibilities to perform effective training of personnel in VR.

Suggestions:

This observation consolidates the prior suggestion of taking measures to upskill relevant personnel in the use of VR.

K2 Summary

There is great variation in VR competence amongst personnel in COWI. There is a number of VR Champions across the organization who are highly competent in the use of VR. On the other hand, most employees do not have thorough knowledge about the range of VR use cases that could be valuable in their projects. Additionally, there is a lack of knowledge about practical use and set-up of VR equipment. These are areas that create a barrier for the use of VR in COWI [2.1.3.2, para 2]. However, the interviews reveal that personnel is interested in learning more about VR, and the current VR capabilities in COWI present opportunities to facilitate upskilling.

Observations show that sporadic initiatives are carried out for upskilling of personnel, implemented primarily by VR Champions. This involves presentations and personal initiatives for facilitating practical training of personnel. Through the interviews, it is revealed that these initiatives have influenced the awareness of VR opportunities amongst personnel. However, the general level of awareness is still low, and lack of time available for learning is creating a barrier for broad dissemination of knowledge. This obstacle needs to be overcome for COWI to successfully utilize the opportunities of VR in the right projects and in a meaningful way [2.4.1, para. 1].

Knowledge is not permanent, and technology is continuously developing, which creates a demand for an enduring process for sustaining the knowledge of personnel. To be able to facilitate sustainable learning and establish lasting, cross-organizational knowledge, a clear plan for the development of VR competency is needed [2.4.2, para. 3]. A suggestion is to organize a centralized unit for the governance of VR initiatives, responsible for gathering and distributing knowledge within the organization. With the current capabilities in COWI, comprised of skilled VR Champions and the VR community site, an excellent foundation for establishing a coherent system for the development of VR is present.

K3 Governance

In this subchapter, observations about the governance of VR initiative in COWI will be presented and discussed. Observations are divided into three areas:

- K3.1 Communication
- K3.2 Strategy
- K3.3 Organization

K3.1 Communication

Studies of early adopters of VR shows that communication is critical in order to spread awareness of VR application and value. This is key in order to overcome the resistance of change within the company [2.1.2.2 & 2.4.3, para. 1]. Through interviews following observation regarding the communication were made:

K3.1.1: Low general awareness of VR opportunities and capabilities in COWI

Explanation:

Observations show that there is low general awareness amongst personnel about the current opportunities to use VR in their work. This concerns both what use cases exist and their benefit, as well as which facilities are available regarding the use of VR in the department. Lack of awareness is a common problem for companies adopting VR [2.4.3, para. 3].

Causes:

The main reason for low awareness about VR is that communication about VR does not reach most personnel [R2]. It is observed that although there is information circling about VR in COWI, very little reaches the vast majority of employees.

As described in K2.1.1, there is personnel with a high degree of knowledge regarding the applications of VR, but there is no systematic knowledge exchange. Due to the lack of a central unit governing VR initiatives, [K3.3.1] knowledge is not gathered and redistributed in an effective manner [2.4.3, para. 3]. This can lead to pools of competence where knowledge is centered on a VR Champion or a skilled VR enthusiast.

There is information located on the VR Community site where all employees of COWI can access it. Here, one may find information about the capabilities of the different offices, as well as how to get more information. The problem here is that most people are not aware of the opportunities that exist on the community site, as only 6% of COWI personnel follows it.

Effects:

Knowing about VR use cases and what value it can bring is the foundation for whether or not to use VR in a project. When most personnel in COWI have low awareness about use cases, in general, it increases change resistance [R3], hampers adoption of VR [2.4.3, para 1 and 3] and by that enhances the barrier to change [K3.3.2].

As described under K1.2.3, it is hard to utilize VR in a project where the project team does not have an understanding of how and why to use VR. This generally low awareness means that in many COWI project the use of VR is not discussed at all, which leads to the use of VR becoming random [K1.1.1] and not based on potential value and need as it should [2.4.1].

The low awareness indicates a lack of information about VR, lack of information has a negative effect on adaptive behavior [2.1.2.2] and in turn, leads to a lower adoption rate. Low awareness of how to use VR and valuable use cases also harms perceived ease of use and usefulness, hampering adoption further [2.1.3.2].

Suggestions:

To be able to enable widespread awareness about VR in the organization, governmental actions are needed. It is recommended that the type of platform for information exchange is extended from primarily community-based interpersonal communication, towards focusing more on mass media channels such as portal advertising as this is more effective when diffusing technologies that are not perceived as very complex [2.1.3.1, para. 7].

K3.2 Strategy

An essential part of top management's role in implementing new technology is aligning the implementation of technology with business goals. Having a strategic focus is vital to gain long-term value from digital technologies [2.4.3, para. 5]. The following observation regarding strategy were made:

K3.2.1 VR fits well with COWI's overhanging strategies

Explanation:

COWI's high-level digitization strategy has several sub-focus areas; one of these is innovation. The two key activities listed under innovation are:

- "Use of new technology and working methods to create new business areas."
- "Utilization of innovative work processes across projects."

The focus for the strategy is digital collaboration and the widespread use of BIM across COWI, and VR is not explicitly mentioned. Having a high-level strategy like this is positive, and the use of new technology should be seen in light of this overall strategy [2.4.3, para. 5].

There are, however, some challenges that must be mentioned. Interviewees expressed a lack of knowledge about the strategic fit of VR and COWI's overall digital strategy. By not sufficiently communicating the overall digital strategy, it may be difficult for employees to see an alignment between VR and COWI's business goals [2.4.3, para. 5]. This may enhance the perception that VR is a short-term gimmick rather than a long-term business opportunity among COWI personnel. Interviewees did also express that VR has had little or no focus by upper management, and no alignment between the use of VR and COWI's overall strategies have been discussed. This lack of management focus on VR [R4] makes the widespread use of VR difficult [2.4.3, para. 2].

Suggestions:

A critical factor in the promotion of technology adoption is focus from management [2.4.3 para. 1]. To be able to align the use of VR in COWI with the overall digital strategy, it is necessary that management is engaged and understands how VR can affect the business [2.4.3, para. 5].

K3.3 Organization

VR adoption is dependent on how well the organization manages to change its workflow in order to accommodate this new technology. This sets requirements for organizational management [2.1.2, para. 1]. During interviews the following observations regarding organization were done:

K3.3.1 No central governance of VR initiatives

Explanation:
In order to ensure the best use of resources and help increase awareness, a centralized unit for governance is ideal [2.4.3, para. 3] Findings from interviews shown no central unit governing COWI's VR initiative. Instead of this, there is a decentralized system where coordination is done in the VR Community at the COWI portal.

Causes:
The VR initiative in COWI started as a bottom-up initiative, meaning that upper management has not been involved with the use and implementation of VR [2.4.3, para. 3]. During further implementation of VR in COWI, upper management has not been actively involved [R4], and no central unit for of governance has been established. Instead, VR Champions lead the implementation of VR.

Effects:
By not having a central unit of governance who can store and exchange knowledge about VR, raising awareness and knowledge spreading becomes difficult, and adoption is hampered [2.4.3, para. 3]. Interviewees expressed that knowledge resides decentralized across COWI, which makes it hard to know how far VR implementation has come and who knows what. There is potential for losing valuable knowledge over time, as best practices and experiences of VR use resides within personnel and is not transferred back to the organization and increasing COWI's capabilities [2.4.2, para. 3].

Suggestions:

It is recommended that a centralized unit for the governance of VR initiatives is developed, responsible for creating awareness, collecting and distributing knowledge about VR throughout the organization [2.4.3, para. 3]. By having a centralized unit, it is possible that best practices from a section in COWI which has come further can aid the implementation of VR elsewhere in COWI, decreasing differences across sections [K1.1.3] and increasing overall adoption rate [2.4.2, para. 3]. This unit should manage resources concerning VR use in COWI as well as administer the development of routines and procedures based on feedback from projects where VR has been utilized.

K3.3.2 Barrier to change current workflow

Explanation:

Changing workflow in an organization is often difficult [2.1.2, para. 1]. Interviewees expressed difficulties in changing current workflows in COWI, where new digital systems and tools were often seen as a distraction and annoyance in day-to-day work rather than a resource. It was further voiced by VR experts that personnel got excited when shown the possibilities of VR use but still did not change their workflow to allow for VR use in projects.

Causes:

Resistance to change is a significant barrier for succeeding in adopting new technology [2.4.3, para. 1]. This resistance comes from many different sources. Some interviewees expressed that COWI employees had difficulties seeing the value and right use cases of VR in construction, something which is typical when implementing VR in a company [2.4.1]. Some interviewees also voiced that in general there is an existing resistance to change current ways of working in COWI [R3], exemplifying this with some personnel not wanting to utilize BIM and 3D modeling and instead use older methods [2.1.2, para. 1].

The need for know-how within the project group to use VR in a project [K1.2.1] and the fact that many in COWI lack knowledge about how to use VR [K2.1.2] help to build this barrier. As of now, employees expressed that projects were tightly scheduled, and that time for training or use of VR technology was not available [K2.2.2]. By not having enough time to learn about and use VR in a project, it becomes hard to change workflow to allow for VR use. In some cases, the lack of available equipment [K4.1.1] also leads to another barrier to change workflow to allow for VR use.

The causes mentioned above lead to VR being viewed as a time-consuming disturbance to the current workflow rather than an improvement. This perception makes it hard to convince personnel about the potential usefulness of VR and represents a barrier for changing workflow [2.1.3.2, para. 2].

Effects:

By not being able to change the current workflow, the use of VR in COWI is not widespread in the company and is limited to only a handful of projects where the project team has VR competency. This slows down further development and adoption across COWI as using VR in projects is a good way to learn and market the use of VR internally. Viewing VR as a disturbance rather than an improvement to current procedures and a lack of understanding of use cases may enhance the perception of VR as a short-term gimmick, as mentioned in K3.2.1. This barrier to change current workflows hampers the overall adoption rate of VR in COWI [2.1.2, para. 1 & 2.3.4, para.1].

Suggestions:

The primary suggestion for reducing barriers to change is to improve the ease of use by developing guidelines and procedures for use, as described in detail in K1.2.1.

It is also suggested to focus on spreading information about VR and the changes in workflow which are to be expected. Being informed about the changes, and why they are happening will decrease general resistance to change, and increase adaptive behavior among employees [2.1.2.2, para 3].

Furtherly, the need for management focus and support for VR initiatives is highlighted once more as this helps signaling to the personnel that VR is a strategic focus point relevant for achieving long term business goals [2.4.3, para. 1].

K3.3.3: VR Champions lead COWI’s VR adoption

Explanation:

Interviewees have expressed that VR Champions are the ones pushing for the use and development of this technology within COWI. These employees are highly adept in the usage of VR technology and listed in the COWI portal as personnel who can be contacted regarding VR use in COWI. From the interviews, it has been made clear that the VR Champions have been crucial for VR adoption in COWI so far. Furthermore, it has been revealed from separate conversations between the authors and VR-adapt personnel in COWI that a research project on VR is currently being carried out. This bottom-up initiative has earned approval for funding and is being performed in collaboration with Aalborg University and Epiito.

Causes:

As mentioned serval times before, VR adoption in COWI has so far been a bottom-up initiative in COWI. When starting to use new technology, it is natural that personnel at lower levels are the first to see value in the technology and start using it [2.4.3, para. 3]. Due to this, upper management might be left out of the loop and lose track of the innovation which occurs in the company.

Because of this lack of focus on VR adaptation in upper management [R4], VR Champions, and other VR adept personnel who are interested in VR currently leading the adoption of VR in COWI.

Effects:

No central governance unit has been established [K3.3.1] that can help with spreading information across COWI [2.4.3, para. 3]. This leads to the VR Champions being the channel which all VR information spreading in COWI goes through. The issue with remaining in this state is that dissemination of knowledge is almost exclusively relying on the enthusiasm of individual VR Champions, which is unpredictable and can lead to an uneven distribution of competence within the organization [K2.1.1]. This will, in turn, lead to uninformed decisions of when to use VR [K1.1.1] in cases were competency is low in the project group, and it can lead to differences in usage between sections [K1.1.3] due to some sections having more active VR champions than others.

It is typical for bottom-up innovation projects to start struggling with continuous growth within the company when more resources are needed [2.4.3, para. 3]. Lack of necessary resources can hamper COWI’s adoption VR and potentially discontinue the whole initiative in the end.

Suggestions:

To achieve widespread adoption of VR technology it is necessary to ensure that development is extended from being solely run by champion initiatives, to a more systematic approach administered by a centralized governance unit (elaborated in K3.3.1).

For upper management to start assessing VR in COWI the findings from the internal research project currently being conducted by VR Champions in collaboration with Aalborg University and Epiito would be a good start. Partnerships like this are a great way of lowering the complexity of VR implementation [2.4.4, para. 3].

K3 Summary

There are several challenges regarding governance of VR that COWI must overcome to succeed with adoption and to improve VR capabilities. Findings show that even though there are VR Champions that are promoting use of VR [K3.3.3], there is still low general awareness about VR in COWI [K3.1.1]. This is a common challenge when adopting VR that hampers adoption rate [2.4.3, para. 3]. The current communication about VR in COWI seems to reach VR Champions and other VR enthusiasts across the company, but not the general employee [R2].

VR in COWI has been a bottom-up initiative from the beginning, with personnel at lower levels of the organization seeing the usefulness of VR and experimenting with the use of it. Top management has not yet addressed the use of VR in COWI [R4], and has let the adoption of VR happen naturally. This is a good way to start the adoption of new technology, but for bottom-up initiatives to succeed it is necessary that they are picked up by management who can align the use of technology with long-term business goals and allocate necessary resources [2.1.2.1 & 2.4.3, para. 3-5].

In order to raise awareness and aid VR Champions in development, it is recommended that a central governance unit is established. This unit will help gather knowledge and experience from different sections and communicate this in order to build awareness [2.4.3, para. 3].

It is furtherly recommended that measures are taken to improve awareness by having a conscious choice of information platform used for internal communication. To be able to reach the vast majority of personnel that are not a part of the VR Community, it is recommended that communication is expanded towards internal mass media channels, as this is an effective measure when diffusing relatively non-complex technology like VR [2.1.3.1, para. 7].

COWI already has an appropriate overall digital strategy that emphasizes on the importance of digitalization of COWI. It highlights that the use of new technology and working methods, as well as the utilization of innovative work processes across projects, are vital parts to COWI's strategic focus. However, in the interviews, a low awareness of the digital strategy in COWI was observed, indicating that it is not adequately communicated. Upper management should ensure that VR is seen in relation to COWI's overall strategy and that the strategy is communicated clearly. This will help emphasize the role of VR as a tool for improving overall efficiency in projects rather than a short term gimmick, and in turn overcome some of the resistance to change [R3] that currently exists with COWI [2.1.3.2 & 2.4.3].

K4 Technology infrastructure

Technology infrastructure is imperative when implementing new digital tools. The state of the current digital infrastructure will affect how easy or difficult it will be to integrate VR as a tool. Several aspects are essential for preparing the company infrastructure in order to ensure rapid and easy adoption of VR technology [2.4.4]. Under this subchapter, technology infrastructure is divided into three sub-areas:

- K4.1 Hardware
- K4.2 Software
- K4.3 Compatibility

K4.1 Hardware

To be able to use VR technology, it is a fundamental requirement that the hardware is accessible. There are many different VR hardware types ranging from simple low-cost equipment to more complex high-cost solutions [2.2.1.1]. For an overview of hardware available in COWI, see Appendix 2. During interviews, the following observations were done concerning hardware:

K4.1.1 Equipment required for use of VR not always available

Explanation:

Interviewees have expressed problems with the graphic cards on current workstation computers at COWI when trying to run VR software. Current computers are optimized for the use of other digital tools such as BIM [2.1.4]. According to interviewees, higher-quality rendering can be achived by using VR a weaker and cheaper G-force graphics card than the current graphic cards used at COWI. This is due to it being more optimized towards VR use.

Additionally, the interviews revealed that while working on projects, employees are often located at a project office rather than the main office. If VR is not part of the delivery, VR equipment is not made available at the project office. There were opportunities to rent VR hardware through the COWI portal, but interviewees expressed that the equipment possible to rent was often limited in amount and not sufficient.

Causes:

If VR is not a part of a delivery, it becomes hard to set aside resources to buy equipment for use in a project office as management has had little to no focus on VR [R4]. The rental option in the COWI portal might be an excellent way of solving this, but interviewees have expressed that it is challenging because the hardware might already be rented out, or that it is spread out in different locations making it more difficult and time-consuming to get hardware to the project office.

Effects:

Lacking necessary equipment decreases the trialability, which affect the rate of adoption negatively [2.1.3.1, para. 4]. It can also give users the impression that VR in itself is challenging to use, which is preventive for future use.

Additionally, tight schedules and budgets in projects make it hard to spend time and resources on acquiring the VR hardware, especially if VR is not part of the delivery. Both these aspects lead to lower perceived ease of use of VR, which in turn creates a barrier for use in projects [2.1.3.2, para. 2].

Suggestions:

To prevent the lack of hardware from prohibiting the use of VR, COWI should map where these deficiencies are, and consider acquiring additional equipment. For example, by investing in laptops with G-force graphics cards that are available for personnel and projects wishing to use VR.

K4.1.2 VR room available at the Oslo office

Explanation:

COWI's office in Oslo has created a designated VR room. This room is available for all employees to rent and contains necessary equipment for VR use. The thought is that it can be used alone, in the project group, as well as with clients. One may contact VR Champions in Oslo to get a tour or get training in using the equipment. Some interviewees expressed that the existence of the room was somewhat under-communicated and that it could be a barrier to use it when having low knowledge about how to use equipment [K2.1.2], due to fear of breaking the equipment.

Causes:

The VR room was launched as an initiative from two VR Champions in COWI [K3.3.3].

Effects:

By lowering the effort needed to try out VR, the VR room significantly increases the trialability of VR, which is described as a critical factor for the adoption of new technology [2.1.3.1, para. 4]. It also lessens the need for knowledge about how to set up VR equipment amongst personnel in this department. Additionally, it presents an opportunity for personnel to be trained in the practical use of VR. This fits well with the finding that 6 out of 8 employees questioned about this wish to learn VR by being taught by someone who knows it well.

Suggestions:

To improve the benefits this VR room can bring about, it is recommended that the possibilities that exist should be clearly communicated across the department. People should also be encouraged to test equipment and pushed to get past the barrier of being afraid of unknown technology.

Further, the establishment of similar VR rooms in the other departments of COWI should be considered, by gathering experiences from the people responsible for the VR room in Oslo.

K4.2 Software

VR has certain requirements concerning software, and because all different software has different strengths and limitations, is it important to evaluate them with respect to company needs [2.2.1.2, para. 1]. For an overview of software that has been reviewed internally in COWI check Appendix 3. During interviews, this observation was found regarding software:

K4.2.1 License cost makes testing and using different software difficult

Explanation:
Technical adept personnel expressed challenges regarding available software. There is a multitude of different software for VR that can be used in the construction industry. One software might be optimal for one section, but less optimal for another. However, most software requires licenses in order to run. With the limitation in resources when VR is not a part of project delivery, it is challenging to attain licenses and test VR or use it in projects where the customer is not paying for VR use.

Causes:
It is problematic to attain funding for licenses without being able to point at specific earnings in return [R5]. This prohibits funding in projects as well as internally in COWI.

Effects:
Lack of licenses prevents the use of VR both because of a lack of money as well as by increasing the threshold to try it out [K3.3.2] and decreasing trialability [2.1.3.1, para. 4].

Suggestions:
A substantial step towards reducing the threshold for the use of VR is attaining organization-wide licenses that cover the relevant use cases in COWI. This can for example be done by entering partnerships with software suppliers. Having software available will increase trialability and in turn, the adoption rate of VR [2.1.3.1, para. 4].

K4.3 Compatibility

In order to reap the full benefit of VR, it is imperative that the current technological infrastructure allows for VR adoption [2.4.4, para. 1]. During interviews following observation were done regarding compatibility:

K4.3.1 VR technology highly compatible with COWI's digital infrastructure

Explanation:

Due to the high level of BIM adoption in COWI, the necessary data needed for developing the virtual environment in VR is easily accessible. In addition to available data, there are several VR software that are either fully integrated or highly compatible with BIM software, making conversion easy [2.3, para. 2].

Effects:

By having data accessible and easily transformed to VR through BIM, the work needed for developing and using VR models is lowered significantly. With sufficient communication of these opportunities, the perceived ease of use is increased and in turn, actual use of VR by personnel [2.1.3.2, para. 2].

K4 Summary

To be able to utilize VR in COWI, the technology infrastructure needs to be put in place. The observations show that existing VR technology is highly compatible with current conditions in COWI, and that technological barriers are primarily limited to how current opportunities are utilized. However, barriers are still observed in the form of a lack of available hardware and software.

Although COWI has acquired a range of VR equipment available for borrowing through the VR Community site in the COWI portal [Appendix 2], lacking hardware availability is seen as a barrier for the use of VR. This includes a lack of equipment present at project offices, as well as limitations in the possibilities of renting equipment. It also includes inadequate graphic cards on working computers that make running VR software difficult and which generate bad experiences that discourage continued use. In order to lower this barrier to VR adoption, it is suggested that deficiencies in hardware are mapped to uncover and satisfy the demand.

In the Oslo department, an initiative is performed by VR Champions to establish a designated VR room on the COWI office. This measure leads to increased trialability of VR, which is essential for the rate of technology adoption [2.1.3.1, para. 4]. In combination with helpful VR Champions, the room facilitates training in the practical use of VR for employees and leads to a reduced need for knowledge about how to set up equipment amongst personnel in this department. It is observed however, that the awareness of the opportunities that exist with this room is not high, and it is suggested that measures are made to increase communication about the possibilities that are present. It is further suggested that similar VR rooms are considered established in the other COWI departments based on experiences gained in Oslo.

Another requirement for the use of VR in COWI is the availability of software programs that apply to COWI's needs. There are several alternatives available, but they all require a license fee for use. There might be a problem with attaining funding for such licenses without being able to quantify how the investment will be paid off [2.3.2, para. 1]. Fees that are relatively insignificant become a barrier for VR use in projects where the budget is tight and can create a certain threshold for trying out VR in projects. It is suggested to consider acquiring licenses that do not charge per use or project. This will reduce the threshold for use and can be a big step towards enabling widespread use of VR and creating a broad consensus about its value.

5. Conclusion

This chapter summarizes the main findings from the analysis, answering how COWI can use VR to create value and how they can improve their VR capabilities. It is divided into the three research questions first presented in chapter 1.2:

- **RQ0: What are valuable use cases for VR in COWI?**
- **RQ1: What is the current state of VR adoption in COWI?**
- **RQ2: What should be emphasized in order to increase COWI's VR capabilities?**

In order to answer the research questions, a qualitative case study has been conducted. Both semi-structured interviews of COWI employees as well as review of internal document has been used as data collection methods.

5.1 RQ0: What are valuable use cases for VR in COWI?

Together with COWI employees, four use cases for VR technology in COWI have been identified. These are design review, simulations, marketing, and sales. Using VR as a visualization tool for design review can either be done with the client and external stakeholders, in cross-discipline meetings with the project team, or alone. Using VR technology may help increase quality, time and cost efficiency, lower risk, and increase the client's ownership towards the project and may subsequently be a competitive advantage for COWI. However, use of VR does require the scarce time of participating personnel, and to be able to acquire the potential benefits VR must be implemented using suitable approaches in appropriate projects.

5.2 RQ1: What is the current state of VR adoption in COWI?

The data analysis resulted in 18 observations of the current state of VR adoption in COWI. The main findings are summarized here, categorized in the four key areas presented in figure 9.

The first key area of observation was the ability to recognize valuable use cases for VR. It was identified deficiencies in the general understanding of potential use cases amongst common personnel. Most employees have an idea of possible use cases, but the knowledge is often scarce and not up to date. Since the decision to use VR lack steering principles and is mostly taken in separate project groups for each project, the VR adoption in COWI become a challenge. As a consequence, the use of VR depends on whether the project group has personnel interested in VR and not on whether it will be beneficial for the project. Furthermore, there is a challenge in quantifying the value gained by using VR [R5], which creates barriers for attaining acceptance for VR adoption.

When it comes to the workforce competency regarding the use of VR, it is observed that considerable amounts of knowledge exist among VR Champions in COWI, but that the general employee is uneducated. VR training for employees is sporadic and unorganized, and personnel within and between sections therefore experience different VR competence levels. The majority of employees express an interest to learn more about VR, however they experience barriers to learn VR in projects due to lack of time.

Concerning the governance of VR technology, findings show that the adoption of VR has so far been a bottom-up initiative. VR Champions are leading the development through individual initiatives, and a research project has been initiated to facilitate further progress. These initiatives represent high developmental capabilities amongst personnel in COWI, an asset that illustrates high technological potential [2.4.3, para. 4]. However, VR has not been addressed in top management, and there is no centralized unit responsible for VR development [R4]. As a consequence, information flows between the already committed personnel on the VR Community site on the COWI portal, but rarely trickle down to other employees. Hence the general awareness and communication about VR lag behind [R2].

Findings about technology infrastructure show that VR technology is highly compatible with the current technological conditions in COWI. The only observed barriers are the sometimes insufficient accessibility of VR equipment and computers that could smoothly run VR software, as well as troublesome issues to attain software licenses.

5.3 RQ2: What should be emphasized in order to increase COWI's VR capabilities?

Research question 1 identified problems with the current performance that could be traced back to five root causes. These five root causes create the basis to identify opportunities for improving COWI's current VR capabilities.

Several issues with the current state of VR adoption stem from a lack of established routines and procedures for implementation and use of VR. In order to enable widespread and effective utilization of VR across the organization, it is crucial to facilitate straightforward and easy-to-use frameworks for both decision making and practical use [2.4.2, para. 3]. It is recommended to create comprehensive and user-oriented guides for using and understanding the application and various use cases for VR. These guides should be made available on the VR Community site.

Furthermore, several issues about the inter-organizational communication about VR was identified. Considerable amounts of information about VR is present amongst competent personnel in the organization. Still, the majority of employees do not receive any information. On the VR Community site there are initiatives to communicate applications and solutions for VR to followers of the community, but there are currently less than 6% of personnel following this site. To be able to establish widespread awareness about VR, it is necessary to broaden communication by extending towards internal mass media channels [2.1.3.1, para. 7]. VR capabilities can be increased by improving the promotion of application possibilities on public communication channels, as capabilities such as practical competency will become improved when VR becomes more widely applied in projects.

A third root cause to barriers for VR adoption is internal resistance to change. Some personnel perceive the adoption of VR as a distraction to the current workflow rather than an improvement. The reason for this can either be that the use case is not valuable for them or it derives from an incorrect perception of the value or the ease of use [2.1.4, para. 2]. Either way, the solution to this problem is to attain better information about the value of the application possibilities and communicate them to employees. This requires both providing confirmation of value [see final paragraph], as well as effectively communicating this to employees as mentioned above. Additionally, it requires developing trialability by establishing facilities for easy use of VR such as VR rooms and necessary equipment [2.1.3.1, para. 4].

Furthermore, a lack of focus on VR from top management is identified. So far, the adoption of VR has happened naturally in COWI, through the initiatives of enthusiastic employees that have started using it in projects. This bottom-up approach is very effective in creating enthusiasm and acceptance among personnel [2.1.2.1, para. 2]. However, to be able to move from a position of sporadic use to a systematic and widespread adoption, it is necessary for management to take a more active role and make sure that the use of VR in COWI is in alignment with long-term business goals. It is recommended that a centralized unit for the governance of VR in COWI is established, responsible for collecting knowledge, spreading awareness, and allocating resources related to VR [2.4.3, para. 3].

The root cause for many challenges regarding VR adoption originates from the issue with quantifying the value of VR. Without being able to evaluate potential value from use cases, it becomes challenging to identify the correct way of application as well as attaining funding for use and acceptance for change. Many benefits are observed from the use of VR in construction, but cost-benefit analyses are often lacking when measuring intangible benefits, such as the quality of the building [2.3.2, para. 1], and it is therefore suggested that the evaluation of VR should be conducted using a more qualitative approach. The establishment of informational feedback loops for projects using VR is recommended to ensure a systematic accumulation of insights about potential VR value. This will enable fact based input for future appraisal and decision making processes [2.4.2, para. 2].

6. Limitations and further research

The purpose of this chapter is to explain the limitations that effects this study, as well as topics that may be studied further.

6.1 Limitations

There are five main limitations to the results in this thesis. The first limitation to this study regards the ability to generalize based on a limited sample size in the data collection, lowering the external validity of this study. As described in chapter 3.3.1, a diverse group of respondents purposively to enable a holistic view of COWI's VR capabilities was chosen. However, the number of respondents was limited to eight in addition to four conversations with experts. Because of this limited number of respondents, it is probable that there is a lack of important perspectives from personnel not interviewed, or that opinions observed are not necessarily the general perception in the departments. Having interviews limited to only two departments can lead to local biases and can exclude essential discoveries that are present in other departments. However, the authors noticed that answers began to be repetitive towards the end of the data collection, which can indicate that perceptions do not vary excessively. Due to pattern matching, and an extensive literature review, the authors feel confident that the results are largely representative and generalizable for COWI Oslo and COWI Trondheim. The authors also regard it as possible that aspects of this study could be generalized for other COWI offices in both in Norway and globally, as well as other companies with similarities to COWI.

Another limitation regards the data collection methods that are used, and in particular, the semi-structured interview approach. As described in chapter 3.3.2, the interview questions are designed to make sure the relevant topics are covered without leading the respondent towards biased answers. As this method enables the respondent to speak freely about the various topics, it also allows them to steer the direction of the interview within the various topics. Because of this, the answers could have been influenced by the interests and perceptions of the respondents. Additionally, it is probable that relevant aspects of the topic are left out of the conversation, diminishing the data collection, and thus limiting the results of the study.

Furthermore, there are limitations to the coding of data obtained. The interviews were transcribed, coded, and refined through a process presented in chapter 3.4.3. Measures were taken to achieve objective coding. However, it is possible that the subjective opinions of the authors have influenced the process. This may have led to biases in the results, which in turn can reduce the replicability of the study.

There is also a limitation in the identification and evaluation of theory for the literature review. VR is still a relatively new area of research, and much of the literature that exists on the topic may have been written by enthusiasts that are biased. However, considerable effort has been put into evaluating the reliability of sources and all literature has been cross-checked. The literature is still subject to interpretation, and it is possible that deviating understandings among the authors has affected the consistency of the literature review. In addition, some of the sources used regarding VR technology in the construction industry are somewhat old and can be partially outdated.

Lastly, due to the fast rate of development of better and cheaper VR equipment, adoption and use may become easier. This can lead to increased usefulness and lower barriers for use, making some of the challenges of adopting smaller than described in this thesis.

6.2 Further research

This thesis is limited to assessing the current capabilities and possibilities of VR adoption within COWI. Other related areas that would be of interest for COWI are Augmented Reality (AR) and Mixed Reality (MR). Currently, these technologies are still relatively immature and poorly adopted in the context of construction. However, the potential is regarded as much higher than with VR, and the widespread adoption of VR can be a steppingstone towards enabling these new possibilities. With high capabilities in VR, this presents an excellent opportunity to be an early achiever in a market that may create a paradigm in the construction industry in the foreseeable future.

There are potentially many more valuable use cases for VR technology in COWI, which this thesis has not identified due to limitation in scope. In addition, VR technology is improving rapidly, potentially enabling new use cases due to technological improvements. It could therefore be interesting to study other potential use cases for VR and their value.

Bibliography

Arayici, Y., Coates, P., Koskela, L., Kagioglou, M., Usher, C., & O'Reilly, K. (2011). Technology adoption in the BIM implementation for lean architectural practice. *Automation in Construction*, *20*(2), 189–195. https://doi.org/10.1016/j.autcon.2010.09.016

Argyris, C., & Schön, D. A. (1978). *Organizational learning*. Reading, Massachusetts: Addison-Wesley Pub. Co.

Attewell, P. (1992). Technology Diffusion and Organizational Learning: The Case of Business Computing. *Organization Science*, *3*(1), 1–19. https://doi.org/10.1287/orsc.3.1.1

Azhar, S. (2011). Building Information Modeling (BIM): Trends, Benefits, Risks, and Challenges for the AEC Industry. *Leadership and Management in Engineering*, *11*(3), 241–252. https://doi.org/10.1061/(ASCE)LM.1943-5630.0000127

Birkinshaw, J., Bouquet, C., & Barsoux, J.-L. (2011). The 5 Myths of Innovation. *MIT Sloan Management Review; Cambridge*, *52*(2), 43–50.

Brand, W. (2015). *Organization Change Management for Dummies*. Hoboken, N.J: Wiley.

Bryman, A. (2016). *Social Research Methods*. New York: Oxford University Press.

Bughin, J., Manyika, J., & Woetzel, J. (2017). *Reinventing construction: A route to higher productivity*. Mckinsey Global Institute.

Burdea, G., & Coiffet, P. (2003). *Virtual Reality Technology* (2nd ed.). Hoboken, N.J: Wiley.

Busch, T. (2013). *Akademisk skriving for bachelor- og masterstudenter*. Bergen: Fagbokforlaget.

Buvat, J., Slatter, M., Pasquet, L., Crummenerl, C., Puttur, R. K., & As, J. van. (2013). *The Digital Talent Gap*. Capgemini Research Institute.

Campbell, D. A. (2007). Building information modeling: the Web3D application for AEC. *Proceedings of the Twelfth International Conference on 3D Web Technology - Web3D '07*, 173–176. https://doi.org/10.1145/1229390.1229422

Chen, K., Lu, W., Peng, Y., Zheng, L., Niu, Y., & Rowlinson, S. (2017). An Investigation of the Latent Barriers to BIM Adoption and Development. In Y. Wu, S. Zheng, J. Luo, W. Wang, Z. Mo, & L. Shan (Eds.), Proceedings of the 20th International Symposium on Advancement of Construction Management and Real Estate (1007–1017). Singapore: Springer,Singapore, https://doi.org/10.1007/978-981-10-0855-9_89

Chen, L., & Luo, H. (2014). A BIM-based construction quality management model and its applications. *Automation in Construction*, *46*, 64–73. https://doi.org/10.1016/j.autcon.2014.05.009

Cohen, L., Buvat, J., Duboé, P., Khadikar, A., Melton, D., & Shah, H. (2018). *Augmented and Virtual Reality in Operations: A guide for investment.* Capgemini Research Institute.

Davies, A., & Hobday, M. (2005). *The business of projects: managing innovation in complex products and systems.* Cambridge; New York: Cambridge University Press.

Davis, F. D. (1985). *A Technology Acceptance Model for Empirically Testing New End-User Information Systems (Doctoral thesis, Sloan School of Management, M.I.T)*. Retrieved from https://www.researchgate.net/profile/Sonam_Mathur2/publication/301824711_Demographic_Influences_on_Technology_Adoption_BehaviorA_Study_of_E-Banking_Services_in_India/links/5aec0c02458515f59981f28c/Demographic-Influences-on-Technology-Adoption-BehaviorA-Study-of-E-Banking-Services-in-India.pdf

Davis, F. D. (1989). Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology. *MIS Quarterly*, *13*(3), 319-340. https://doi.org/10.2307/249008

Davis, F. D, Bagozzi, R. P., & Warshaw, P. R. (1989). User Acceptance of Computer Technology: A Comparison of Two Theoretical Models. *Management Science, 35(8), 985. https://doi.org/10.1287/mnsc.35.8.982*

DeLone, W. H., & McLean, E. R. (1992). Information Systems Success: The Quest for the Dependent Variable. *Information Systems Research*, *3*(1), 60–95. https://doi.org/10.1287/isre.3.1.60

Derbyshire, A. (2001). Probe in the UK context. *Building Research & Information*, *29*(2), 79–84. https://doi.org/10.1080/09613210010016839

Eadie, R., Browne, M., Odeyinka, H., McKeown, C., & McNiff, S. (2013). BIM implementation throughout the UK construction project lifecycle: An analysis. *Automation in Construction*, *36*, 145–151. https://doi.org/10.1016/j.autcon.2013.09.001

Eastman, C. M., Teicholz, P., Sacks, R., Liston, K. (2008). *BIM handbook: a guide to building information modeling for owners, managers, designers, engineers, and contractors*. Hoboken, N.J: Wiley.

Emborg, J. S., & Sekse, M. (2018, January 23). virtual reality kan skape besparelser i kompleks infrastruktur og bygg og anlegg. Retrieved June 5, 2019, from COWI website: https://www.cowi.no/innsikt/ny-studie-virtual-reality-kan-skape-besparelser-i-kompleks-infrastruktur-og-bygg-og-anlegg

Fernandes, K. J., Raja, V., White, A., & Tsinopoulos, C. D. (2006). Adoption of virtual reality within construction processes: a factor analysis approach. *Technovation*, *26*(1), 111–120. https://doi.org/10.1016/j.technovation.2004.07.013

Forbes, L. H., & Ahmed, S. M. (2010). *Modern Construction: Lean Project Delivery and Integrated Practices*. Boca Raton: CRC Press.

Forni, A. (2017). Transform Business Outcomes With Immersive Technology. Retrieved May 12, 2019, from https://www.gartner.com/smarterwithgartner/transform-business-outcomes-with-immersive-technology/

Hidi, S. (1990). Interest and Its Contribution as a Mental Resource for Learning. Review of Educational Research, 60(4), 549-571. https://doi.org/10.3102/00346543060004549

Holloway, M., & Carusi, D. (2015). *Organizational Change Management for dummies Deltek Special Edition.* Hoboken, N.J: Wiley.

Jacobsen, D. I. (2018). *Organisasjonsendringer og endringsledelse*. Bergen: Fagbokforlaget.

Jacobsen, D. I., & Thorsvik, J. (2007). *Hvordan organisasjoner fungerer*. Bergen: Fagbokforlaget.

Jiao, Y., Zhang, S., Li, Y., Wang, Y., & Yang, B. (2013). Towards cloud Augmented Reality for construction application by BIM and SNS integration. *Automation in Construction*, *33*, 37–47. https://doi.org/10.1016/j.autcon.2012.09.018

Kane, G. C., Palmer, D., Phillips, A. N., Kiron, D., & Buckley, N. (2015). Strategy, not Technology, Drives Digital Transformation. *MIT Sloan Management Review*. Retrieved from https://sloanreview.mit.edu/projects/strategy-drives-digital-transformation/

Kerravala, Z., & Miller, L. C. (2017). *Digitalization for dummies, Mitel Special Edition*. Hoboken, N.J: Wiley.

King, W. R., & He, J. (2006). A meta-analysis of the technology acceptance model. *Information & Management*, *43*(6), 740–755. https://doi.org/10.1016/j.im.2006.05.003

Kodama, F. (1995). *Emerging patterns of innovation: sources of Japan's technological edge*. Boston: Harvard Business School Press.

Leaman, A., & Bordass, B. (2001). Assessing building performance in use 4: the Probe occupant surveys and their implications. *Building Research & Information*, *29*(2), 129–143. https://doi.org/10.1080/09613210010008045

LeCompte, M. D., & Goetz, J. P. (1982). Problems of Reliability and Validity in Ethnographic Research. *Review of Educational Research*, *52*(1), 31–60. https://doi.org/10.2307/1170272

Maldovan, K., & Messner, J. I. (2006). Determining the effects of immersive environments on decision making in the AEC Industry. In Joint International Conference on Computing and Decision Making in Civil and Building Engineering, 2762-2770.

Mealy, P. (2018). *Virtual & augmented reality for dummies*. Indianapolis: Wiley.

Murray, E. J., & Richardson, P. R. (2003). Fast Forward: A new framework for rapid organizational change. *Ivey Business Journal*, *67*(6), 1–6.

Nikula, U., Jurvanen, C., Gotel, O., & Gause, D. C. (2010). Empirical validation of the Classic Change Curve on a software technology change project. *Information and Software Technology*, *52*(6), 680–696. https://doi.org/10.1016/j.infsof.2010.02.004

Oreg, S. (2006). Personality, context, and resistance to organizational change. *European Journal of Work and Organizational Psychology*, *15*(1), 73–101. https://doi.org/10.1080/13594320500451247

Paes, D., Arantes, E., & Irizarry, J. (2017). Immersive environment for improving the understanding of architectural 3D models: Comparing user spatial perception between immersive and traditional virtual reality systems. *Automation in Construction*, *84*, 292–303. https://doi.org/10.1016/j.autcon.2017.09.016

Parviainen, P., & Tihinen, M. (2017). Tackling the digitalization challenge: how to benefit from digitalization in practice. *IJISPM - International Journal of Information Systems and Project Management*, *5(1)*, 63–77. https://doi.org/10.12821/ijispm050104

Proverbs, D. G., Holt, G. D., & Cheok, H. Y. (2000). Construction industry problems: the views of UK construction directors. In Akintoye, A (Ed.), 16th Annual ARCOM Conference, 6-8 September 2000, 73–81.

Rogers, E. M. (1995). *Diffusion of innovations* (4th ed). New York: Free Press.

Sahin, I. (2006). Detailed review of Rogers' diffusion of innovations theory and educational technology-related studies based on Rogers' theory. *The Turkish Online Journal of Educational Technology*, 5(2), 14-23.

Sampaio, A. Z. (2018). Enhancing BIM Methodology with VR Technology. In N. Mohamudally (Ed.), *State of the Art Virtual Reality and Augmented Reality Knowhow,* 59–79. https://doi.org/10.5772/intechopen.74070

Schneider, D. M., & Goldwasser, C. (1998). Be a model leader of change. *Managment Review; New York*, *87*(3), 41–45.

Sharma, A., Gröne, D. F., de Souza, I., & Koster, A. (2011). Measuring industry digitization: Leaders and laggards in the digital economy. Retrieved from https://www.strategyand.pwc.com/media/file/Strategyand-Measuring-Industry-Digitization-Leaders-Laggards-Digital-Economy.pdf?fbclid=IwAR3ojsQ2zeGLTEWRUUnZvs2dWGIGChKMeb_c2TKcANLE31OcB4m4kWp_9E0

Strauss, A. L., & Corbin, J. M. (1998). *Basics of qualitative research: techniques and procedures for developing grounded theory* (2nd ed). Thousand Oaks: SAGE Publications.

Sundukovskiy, S. (2018, March 7). Update on construction technology trends. Retrieved May 6, 2019, from Chain Store Age website: https://www.chainstoreage.com/store-spaces/construction-technology-trends-embrace/

Thabet, W., Shiratuddin, M. F., & Bowman, D. (2002). Virtual Reality in Construction: A Review. In B. H. V. Topping & Z. Bittnar (Eds.), *Computational Science, Engineering & Technology Series* (Vol. 8, pp. 25–52). https://doi.org/10.4203/csets.8.2

Thomke, S. H. (1998). Simulation, learning and R&D performance: Evidence from automotive development. *Research Policy*, *27*(1), 55–74. https://doi.org/10.1016/S0048-7333(98)00024-9

van den Heuvel, M., Demerouti, E., Bakker, A. B., & Schaufeli, W. B. (2013). Adapting to change: The value of change information and meaning-making. *Journal of Vocational Behavior*, *83*(1), 11–21. https://doi.org/10.1016/j.jvb.2013.02.004

Wanberg, C. R., & Banas, J. T. (2000). Predictors and outcomes of openness to changes in a reorganizing workplace. *Journal of Applied Psychology*, *85*(1), 132–142. https://doi.org/10.1037/0021-9010.85.1.132

Whyte, J. (2002). *Virtual reality and the built environment*. Oxford: Architectural Press.

Whyte, J., & Bouchlaghem, D. (2002). Implementation of VR systems: a comparison between the early adoption of CAD and current uptake of VR. *Construction Innovation*, *2*(1), 3–13. https://doi.org/10.1108/14714170210814658

Woksepp, S. (2007). *Virtual reality in construction: tools, methods and processes* (Doctoral thesis, Luleå University of Technology). Retrieved from http://www.diva-portal.org/smash/record.jsf?pid=diva2%3A999878&dswid=-8852

Yin, R. K. (2012). *Applications of case study research* (3rd ed). Thousand Oaks, California: SAGE Publications.

Yin, R. K. (2014). *Case study research: design and methods* (5th ed.). Los Angeles: SAGE Publications.

Zimmerman, A., & Martin, M. (2001). Post-occupancy evaluation: benefits and barriers. *Building Research & Information*, *29*(2), 168–174. https://doi.org/10.1080/09613210010016857

Appendices

Appendix 1: Interview guide

Introduction (Translated from original language)

Hi.

We are two students from the University of Stavanger who are studying industrial economics. We are currently writing a master's thesis on the use of VR in the construction industry and want to map how COWI is using VR.

We have three research questions that we want to answer, which are:
- How may VR be used in COWI to create value?
- How is VR technology used in COWI today?
- What should be emphasized to increase COWI's VR capabilities in the future?

To investigate this, we interview personnel from various departments in COWI. We do take transcribe this interview, but the content will not be used directly in the thesis. Your feedback will be seen together with the other interviews and create the basis for collective observations that will be the basis for further discussion. Interviewees will also be anonymized.

The primary intent of the research is that COWI will gain a better understanding of how today's VR capabilities are and what should possibly be improved.

In order to get a holistic view of the current state of VR adoption and use of VR in COWI, we are going to ask questions regarding 4 areas.
- Use cases and value
- Workforce competency
- Governance
- Technology infrastructure

It is probable that all areas may not be relevant to you, as we interview people with different backgrounds who have expertise in different areas. So if you feel that you are not able to answer the question, just let us know.

We are going to ask some open questions that have no correct answer, and that will concern your experiences from working in COWI. If you feel that a question is unclear, just ask us to elaborate.
If this sounds okay, then we will get started.

Interview questions

Table 5: Interview Guide

Area	Questions
Intro.	- Tell us a little about yourself and your role in COWI. - How is your experience with using VR?
Use cases and value	1. First, we want to investigate how decisions are made regarding which projects will use VR and how it will be used. Can you tell a little about how and in what projects COWI uses VR today? a. Do you see any use cases for VR in COWI? -> Which? b. How is it decided whether VR will be used in a project and how extensive it will be used. c. Are there any guidelines for the use of VR? d. How do you rate the value of using VR in a project?
Competency	2. We want to talk about the current VR competency within COWI. Can you tell a bit about how do you perceive the general VR competence among relevant personnel in your department? - Knowledge of its value and its technical requirements - Practical knowledge and experience with the use of model and conversion from a BIM model a. What would you regard as the biggest obstacle for the use of VR in a project? b. Are there any areas where competence is lacking? -> What? c. Do you have any approach to respond to a lack of VR expertise? d. Would you like to learn more about VR? -> How?
Governance	3. We want to gain an understanding of how the VR initiative in COWI is governed. Could you tell us about how VR technology is organized and coordinated in COWI? a. What is the organizational structure for VR competence? b. What would you say that COWI's strategy for using VR is? c. Should you need information on VR, how would you obtain it? d. How would you say the communication about the use and potential of VR technology in COWI is? e. Internal -> How is general awareness? f. External -> How is VR communicated towards the customer?
Technology infrastructure	4. Can you tell us about technological barriers when using VR in COWI? - How easy/difficult is it to get the data necessary for using VR? a. How are the needs for collaboration in the VR model, and how does it affect the technical requirements? - Is COWI conscious of their needs? - Necessary network capacity? - Required computer power?

	b. Are COWI collaborating with other companies regarding VR initiatives? c. How does VR technology match the total digitization of COWI? - How easy/difficult is it to integrate VR technology with COWI's current digital infrastructure? - Is VR Integrated into an Enterprise Resource Planner?
Final comment	- Something to add? - How are the questions? - Anything more that should be asked?

Appendix 2: VR hardware

Table 6: VR equipment available for COWI employees, adapted from VR community at COWI-portal.

Name	**CAVE**	**Oculus Rift**	**HTC Vive**	**Samsung Gear VR**	**BOBOVR Z4**	**Homidi mini VR**
Requirements	Specialized set up dependent on need/cost	Powerful PC/laptop	Powerful PC/laptop, Dedicated meeting room	Samsung Galaxy 6 or 7	A smart phone	A smart phone
Possible extensions	Dependent on solution.	Oculus touch controller, Xbox one controller	None	Nimbus SteelSeries controller	Nimbus SteelSeries controller	None
Cost	Dependent	3600 – 5000 DKK	N.D	500 DKK	50-750 DKK	410DKK for 10
Comments on use		Used with heavy PCs (min. requirement is COWI 17" laptop) to present panoramas, walk-through models etc.	Alternative to Oculus Rift, but better suited for dedicated meeting rooms due to required installation.	Used with Samsung Galaxy S6 + S7 to view panorama images and relatively simple walk-through models	Used with all phones to view panorama images and relatively simple walk-through models	

Appendix 3: Relevant VR software

Table 7: VR software tested in COWI. Adapted from COWI TRY report from 2017

Name	Price NOK/year	Pros	Cons
Autodesk Live	4 000-16 000	Adjustable height, wheelchair, graphics, Revit and Stingray	Known issues with crashes, no fly or walk mode and only teleporting from different location
Enscape	3 600-5 200	Live Revit update, cheap, easy to use, better rendering than Revit	Revit support and visualization only
Fuzor	16 000-26 000	Clash detection, weather simulation, AR, most features in VR, supportive, bi-directional link, avatars	Training manual, no dynamic movement in simulation
Revizto	40 000-123 000	Supportive, easy to navigate, issues tracker/forum, collaboration	Graphics, limited features in VR, no