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Author: Vikrant Kaushal	(signature of author)
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Exploratory Study: Implementation and Applications of Extended Reality

By Vikrant Kaushal
University of Stavanger
Department of Mechanical and Structural Engineering and Materials Science

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Preface

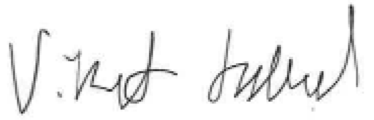
This thesis marks the end of a five-year endeavour to obtain a Master of Science in Engineering Structures and Materials at the University of Stavanger. It has been researched and written from January to June 2019.

The choice of topic has been influenced by my interest in new technology, my future employer and how to further develop my knowledge in a field that has the potential to become a fundamental part in the future of engineering. The thesis does not rely on theory obtained in courses, it required me to immerse myself in to a whole new topic. Doing so, there has been no shortage of challenges. To overcome these challenges, special thanks are owed to my academic supervisor, Prof. Chandima Ratnayake (UiS) and external supervisor, Roar Fosse (Skanska).

I would also like to thank all interview subjects. Without you, there would be no thesis.

A special thanks is owed to my fellow students for making the last five years as memorable as they have been.

Lastly, I would like to give a quick shoutout to my family and the homeboys back in the hood. Lets get this bread boys.



Vikrant Kaushal

Forord

Denne masteroppgaven markerer avslutningen på min målsetning om å få en mastergrad i teknologi i Konstruksjoner og Materialer ved Universitetet i Stavanger. Oppgaven har blitt utarbeidet fra Januar til Juni 2019.

Valget av emne har blitt påvirket av min interesse for ny teknologi, min fremtidige arbeidsgiver, samt ønsket om å videreutvikle min kunnskap innenfor et fagfelt som potensielt kan bli fundamentalt innenfor ingeniørarbeid. Oppgaven bygger ikke på teori fra fag, noe som har krevd fordypning innenfor et helt nytt fagfelt. Det har derfor ikke vært knapphet på utfordringer. Professor Chandima Ratnayake (UiS) og min eksterne veilder Roar Fosse (Skanska) fortjener en ekstra takk for deres arbeid i å hjelpe meg med å løse disse utfordringene.

Jeg ønsker også å takke alle intervjuobjekter. Uten dere ville det ikke blitt noen oppgave.

Uten mine medstudenter på studiet ville ikke de siste fem årene vært så bra som de har vært. Takk for alt.

Til slutt vil jeg bruke denne muligheten til å gi en liten shoutout til familien og gutta hjemme.

Vikrant Kaushal

Summary

It is well known that the construction industry has the potential to increase its productivity. It is also well known that a solution can be to assess decisions made early in a project more thorough, as these decisions permeate the entirety of the project. By making the correct decisions early in a project, a positive effect on the project deliveries will be observed. Research has been carried out to establish how Extended Reality can benefit the construction industry, both now and in the future. The entire project phase has been considered but the focus is on the early project phase.

The research was carried out using a literature review and several interviews with people from the construction industry. Three interview groups have participated: A construction project group from Skanska, several members of Skanskas BIM/VDC department, and two employees of the engineering consulting company Niras. Findings have been presented, discussed and qualitatively evaluated with the problem description as the premise.

Technology relevant to the thesis have been presented. Theory and principles of XR have been discussed, and the benefits of XR over conventional means of information transfer have been established.

Current and future areas of use of XR technology has been researched. Factors believed to be critical for a successful implementation of these areas of use have been identified. This work relies heavily on the comparison with other industries, but are also based on the results from interviews and literature. While this thesis proposes concrete measures believed to be critical to ensure a successful implementation, it can not be certain in its proposals. This is due to the large variation in the information provided by interview objects and by available literature. This thesis rather touches several interesting topics that should be further researched.

Sammendrag

Faglitteratur og fagfolk annerkjenner at byggebransjen har et forbedringspotensiale når det kommer til produktivitet. Det er også annerkjent at en potensiell løsning er å vurdere avgjørelser gjort i tidligfasen av et prosjekt grundigere, siden disse avgjørelsene følger prosjektet gjennom hele gjennomføringen. En positiv effekt på prosjektleveransene kan observeres ved å fatte de korrekte avgjørelsene tidlig i et prosjekt. Forskningsarbeid har blitt gjort for å avgjøre hvordan Utvidet Virkelighet (Extended Reality) kan forbedre byggebransjen, både nå og i fremtiden. Hele prosjektfasen har blitt vurdert men fokuset er på tidligfase.

Forskningsarbeidet har blitt utført ved hjelp av litteraturstudie og intervjuer med folk fra byggebransjen. Tre intervjugrupper har deltatt: En prosjektgruppe fra Skanska, flere medlemmer fra Skanskas BIM/VDC avdeling, og to ansatte ved Niras, et ingeniørrådgivende selskap. Funn fra forskningsarbeidet har blitt presentert, diskutert og kvalitativt evaluert i mot problemformuleringen.

Teknologi relevant for oppgaven har blitt presentert. Teori og prinsipper omhandlende XR har blitt diskutert, og fordelene ved XR i motsetning til tradisjonell teknologi for informasjonsdeling har blitt identifisert.

Nåværende og fremtidige bruksområder for XR har blitt undersøkt. Faktorer ansett som kritiske for implementasjon av XR har blitt identifisert. Arbeidet tilknyttet dette bygger i stor grad på sammenligning med andre bransjer, men også på resultater fra litteraturstudiet og intervjuer. Oppgaven foreslår konkrete tiltak for å sikre en god implementering men kan ikke anbefale disse uten forbehold. Dette grunnet den store variasjonen i informasjon innhentet fra intervjuobjekter og tilgjengelig litteratur. Oppgaven identifiserer heller flere temaer som anses som interessante. Disse temaene bør undersøkes videre.

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Abbreviations

AEC	Architecture, Engineering and Construction
AR	Augmented Reality
BIM	Building Information Modelling
CAD	Computer Aided Design
GNSS	Global Navigation Satellite System
HMD	Head Mounted Display
HSE	Health, Safety and Environment
LPS	Last Planner System
MR	Mixed Reality
VDC	Virtual Design and Construction
VR	Virtual Reality
XR	Extended Reality
4D	Building Information Modelling incorporating time.
5D	Building Information Modelling incorporating time and cost.

Chapter 1

Introduction

This chapter will introduce the reader to the contents of this thesis, how the topic has been chosen, what the thesis will focus on and limiting factors.

1.1 Background

In any project, the cost of change rises the further along a project has come, while the ease of implementing change drops [1]. By minimizing change and ensuring that all parties involved agree upon the design, the risk of cost- and time overruns may be mitigated.

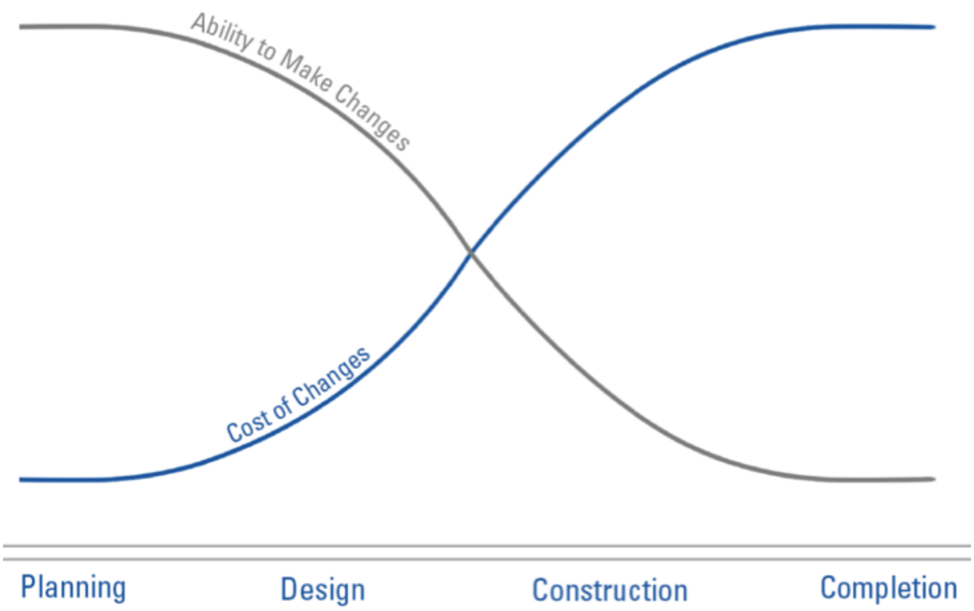


Figure 1.1: Correlation between cost of change and the ability to make changes [2].

The construction industry in general is infamously known for precisely time and cost overruns [3]. In construction, behind schedule can be defined as the completion of a task or the project as a whole later than agreed upon. This agreed upon deadline can be defined in the contract, by a manager on site or by the project owner. Considering the project in its entirety, being delayed will mean a loss of revenue for the owner, since the project is not operational at the agreed upon time. For the contractor, a delay will result in higher overhead costs and potential fines. Assuming all parties involved acts ethically and the contract type is logical, everyone involved in a project will benefit when it is delivered on time and on budget. Unfortunately, deviations from the original design are common in most construction projects. Contract modifications due to design changes that increase the contract value from 5 to 10% are expected in most construction projects [4].

A cost overrun can in many ways be considered as an equal to a time overrun. Being unable to solve a problem properly will likely result in an overrun, be it cost or time. In the context of this thesis the source for one will be considered as a source for both.

1.2 Terminology

In this section, a brief explanation of crucial terminology used throughout the thesis will be given. They will be further elaborated later, in chapter 3.

XR: Extended Reality. A collective term for technologies that enables information to be conveyed by computer-generated environments that are to some degree immersive [5].
VR: Virtual Reality. Virtual Reality is a fully immersive computer-generated virtual environment which the user can in some way interact with [6].
AR: Augmented Reality. Augmented Reality allow users to see the real world, with virtual objects superimposed upon or composited with their real environment [7].

1.3 Problem description

In collaboration with Skanska Norway, this thesis will evaluate the potential of XR technologies to improve the cost- and time efficiency of the construction industry. This is done by considering current and future construction industry applications of XR technologies, and how these applications will influence the construction process.

This thesis will hopefully function as an informative document in which the reader is presented with information about the possibilities of extended reality in a construction industry context.

1.4 Scope

This section will define the scope of the thesis.

Extended reality already has multiple areas of use in the construction industry. As the technology matures, more and more applications will appear. These areas need to be researched, their effect documented and feasibility studies should be carried out. In other words, there are several research areas to consider with regards to XR in construction. This thesis can not cover all areas.

This thesis will focus on mapping out current and future areas of use of XR in the construction industry, and look at potential risks and opportunities when considering these areas of use. Requirements for successful implementation will be researched and presented as well.

The explicit workings of the technology such as the link between software and hardware will not be investigated in detail. This thesis will focus on applications and the actual use of the technology.

1.5 Limitations

This section presents the limiting factors for the thesis.

The most prominent limitation is the lack of literature. Plenty of theory exist on the topics of VR and AR, but there is relatively little literature about the use of XR in the construction industry. Whatever literature exists mainly consist of small-scale experiments carried out by education institutions. Such literature certainly provides some usable theoretical foundation but there is no doubt there is a difference between controlled testing and full-scale use on a construction site. The lack of such theory arguably demonstrates the need of further research such as this thesis.

The lack of literature may be considered a symptom of another limiting factor: The lack of use. After conducting interviews with people that can be considered experts in the field of XR in the construction industry, it was surprising to hear how limited the use of XR actually is. Before starting this thesis, the author expected the use was to a degree where most AEC (Architecture, Engineering and Construction) professionals had been on a project using the technology. This was revealed to be far from reality. This lack of use leads to a lack of experience. This leads to interview subjects stating the same. This is beneficial in terms of referencing and confirming a viewpoint but leads to a lack of variation in experiences.

There exists very limited theory about XR in the Norwegian construction industry. Even though the thesis considers Skanska Norway it can be considered relevant for the industry as a whole. Sources are therefore not limited to Norway or Skanska.

XR in construction is not a new concept but has just recently gained some traction. The field is undergoing rapid development with new technology being introduced frequently. For these reasons, newer sources have been prioritized, mainly publications from 2015 to today.

Another limitation is the interview subjects. They have been treated as reliable sources, considering their experience with the industry. This means that their personal experience may contradict some literature.

When discussing future applications of XR, it becomes clear that a technological breakthrough in visualization technology alone is not enough. To be able to apply XR to the proposed future applications, technological progress is also needed in other fields, such as location determination and image recognition technology [8]. These other technologies will not be discussed in detail.

1.6 Research methodology

Literature review

The primary goal of Chapter 3 was to do a broad literature review of available theory on relevant topics to have a sound theoretical foundation to build on. This was done by searching through various databases online and using relevant literature in the university library. In Chapter 5, the primary goal was to identify current and future applications of XR. To do this, a more comprehensive literature review was undertaken and findings combined with the results from the interviews.

Information, especially the one available online, can be somewhat problematic to include in a literature review. Anyone can publish whatever they want online. An attempt has been made to verify information by cross-checking it and only include verified information in this thesis. Another measure taken to ensure verified information is attempting to retrieve as much information as possible from credible sources.

Interviews

The interviews were carried out by following a template (Appendix). The template was designed to be suitable for all interview subjects, independent of their experience and background. Discussions with thesis supervisors were used to establish the interview questions. The suggestions made in question 3 ("What have you used XR for? If suggestions are needed:") are based on available literature about areas of use that have been tested to some degree. An attempt was made to keep the interviews flowing as a natural conversation while at the same time obtaining answers to all questions. This was done to allow interview subjects to share whatever they believed to be relevant for the conversation and by that, obtaining information not directly asked for that could be useful.

An interviewer can be selective when communicating with interview subjects. The interviewer can chose what information to present to interview objects, as well as be selective with the information they register. This has the potential to be a significant source of error. The interviewer can also be biased, thereby consciously or unconsciously leading interview subjects to answer in a manner that does not reflect their own opinion but rather, the interviewer's opinion. This phenomenon is known as confirmation bias [9]. The author (as an interviewer) has attempted to remain neutral and let interview subjects answer however they see fit but the possibility of an unconscious bias may exist.

The interviews were recorded and took between 10 and 40 minutes. The interviews are presented as summaries in the Appendix and are not direct quotations. Some interview subjects were unable to provide answers to certain questions and are therefore left unanswered.

Chapter 2

Method

In this chapter, a short description of the method and research design used in this thesis will be given. A method explains how the work has been carried out to solve a problem and how it will influence results, conclusions and further work [10]. According to McGaghie et al. [11], research design has three main purposes:

"(1) to provide answers to research questions, and (2) to provide a road map for conducting a study using a planned and deliberate approach that (3) controls or explains quantitative variation or organizes qualitative observations."

Advantages, disadvantages and why exactly these methods have been selected will be discussed. The reason to include this is to provide the reader with the basis and theoretical background for the conclusions made in the thesis [10].

2.1 Qualitative and quantitative method

Qualitative studies use human experience and interpretation to gather non-numerical data and provide a conclusion that may answer a "why" or "how". Quantitative studies use quantifiable measures, for example how many, and are more applicable to traditional scientific research. The formulation of a problem where a qualitative method is suitable is usually more open than for a quantitative method. A qualitative method relies on so-called soft data such as interviews and observations, while a quantitative method relies on hard data such as numbers or graphs [12].

A difference in qualitative and quantitative methods is the reliability of the results. Reliability can be defined as the degree of variance in the results of a test or procedure, when repeated [13]. Since qualitative measurements relies on human experience and non-numerical data, it follows that the reliability of such measurements is lower than for quantitative methods that relies on numerical data. It can be argued that reliability is an unnecessary, or even misleading concept in qualitative research. If the reliability is used as a measurement of the quality of a study, it will most likely be classified as a low-quality study despite the fact that it may provide valid information [14].

Validity is another measurement of quality in research. For quantitative research, validity can be defined as whether the research measures the intended parameter or how truthful the measurements are [12]. Validity is often determined by comparing findings to the research of others. Determining the validity of qualitative research can, by the nature of validity, be challenging. Qualitative studies do not aim to measure anything; measuring the quality of a qualitative study based on validity is therefore meaningless [15]. Access has been suggested as a measurement of quality in qualitative studies instead. In this context, access means the possibility and ability to come close to the phenomenon under study [14]. The researcher must display transparency in how they have obtained knowledge and be open about potential biases. This is done to increase the trustworthiness of the researcher [12].

2.2 Inductive and deductive reasoning

A quick and simple way to describe these terms is that inductive reasoning uses something specific as a basis and has a general conclusion, while deductive reasoning does the opposite; it goes from the general to the specific [16]. Inductive reasoning recognizes patterns and makes generalizations to answer a well-defined problem. The answer is usually not as well defined and easy to understand as the problem and often the conclusion is a form of hypothesis or theory. As an example of inductive reasoning, consider a bag of twenty apples. If you pull out 3 apples that are all red, your conclusion based on inductive reasoning is that all apples in the bag are red. By considering another example, the nature of inductive reasoning is further demonstrated. Consider the same bag of twenty apples. Another conclusion based on inductive reasoning could be that all bags contain apples. This does not sound plausible or reasonable. This is due to the fact that inductive reasoning heavily relies on our knowledge of the world [17].

Deductive reasoning can be described as applying a theory or hypothesis to a problem and testing it [16]. It relies on the fact that all premises are true. An example could be "All men are mortal, therefore Vikrant must be mortal". If the hypothesis is that Vikrant is mortal then this is valid deductive reasoning since it is true that all men are mortal.

2.3 Develop knowledge and propose action

The purpose of most master theses is either to develop knowledge in a certain field by conducting research or propose actions to reach a desirable outcome [18]. To develop knowledge, research is carried out and new knowledge might be obtained but the researcher does not necessarily propose how this knowledge should be used in the best way [19]. The reason to develop knowledge is usually to provide new information that can support a proposed action. Let us say that a river must be crossed and it has been established that a bridge is the best way to do it. This does not mean that it can be built right away. Knowledge about the project and surroundings must be obtained. Proposing an action would be to do it the other way around. It is about utilizing knowledge to find a new or better use of said knowledge. An example of "re-using" knowledge is XR, more precisely VR. The VR in use today was originally developed for gaming but other industries such as the medical industry and construction industry have recognized the opportunities this technology presents.

Even though this thesis is not meant to develop new knowledge, it does gather knowledge from different sources. Hopefully, this presents some information that was previously unknown to all readers.

2.4 Method of choice

"A good qualitative study can help us understand a situation that would otherwise be enigmatic or confusing" [20].

"Inductive reasoning combines the observation and the explanation to infer the rule and thus, moves from the particular to the general" [21].

Considering the purpose and scope of this thesis as well as the information available about the topic in question, a qualitative method using inductive reasoning will be used to propose actions that will enable Skanska to identify potential opportunities and pitfalls regarding XR.

A qualitative method is chosen over a quantitative one due to the problem description and available literature. The problem description is fairly open and does not have a single, easily defined answer. The literature available is dominated by qualitative literature and very little quantitative literature exists.

Inductive reasoning will be used since it is more compatible with a qualitative method [19]. This thesis will present its findings based on the generalization of information gathered in interviews. The findings will comprise of varying information based on the same inquiry.

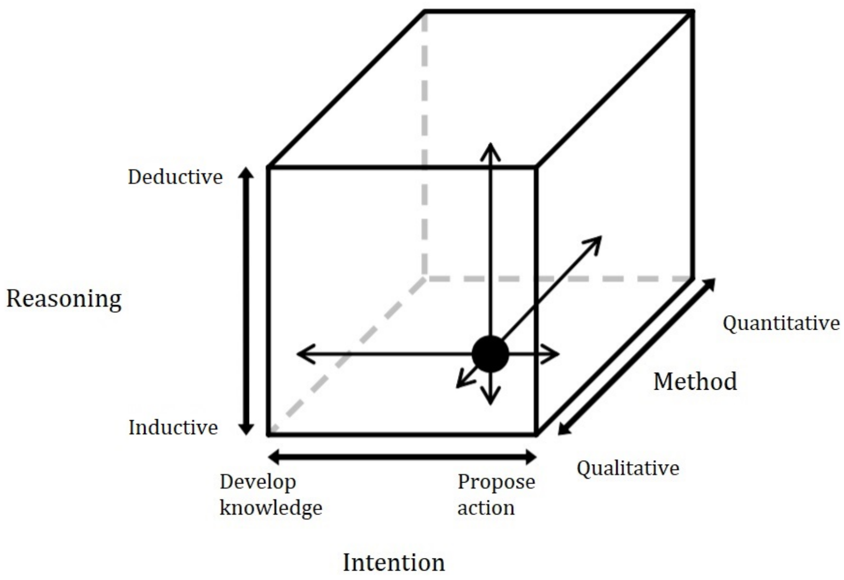


Figure 2.1: Approach to the problem [18].

Chapter 3

Theory and Technology

The main subject of this chapter will be a theoretical introduction to Extended Reality and an explanation of terminology and principles that are vital to the thesis. The chapter will also present hardware and software relevant for the construction industry.

3.1 Extended Reality

Extended Reality (XR, also called Cross Reality) is a collective term for technologies that enables information to be conveyed by computer-generated environments that are to some degree immersive [5]. The most common technologies under this umbrella term are Augmented Reality (AR), Virtual Reality (VR) and Mixed Reality (MR). It is important to understand that these terms do not have easily identifiable boundaries but rather floats together. A technology is categorized under one of these terms depending on the degree of immersion. This is not limited to visual immersion but can also include audio, haptics and other stimulation of senses. In terms of relevance for the construction industry, only visual extended reality is currently relevant and somewhat developed.

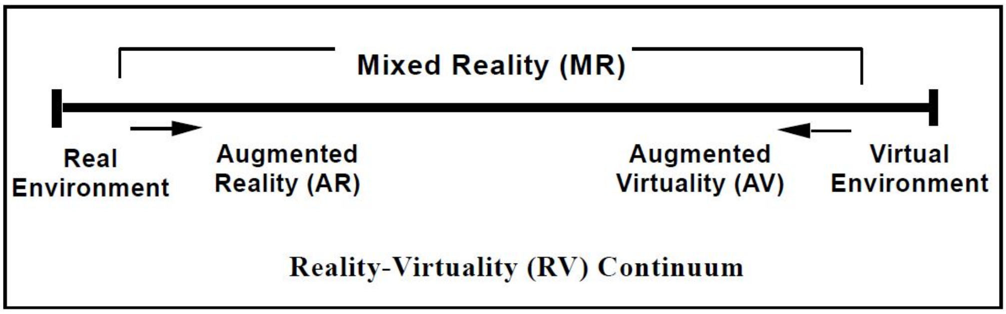


Figure 3.1: The reality-virtuality continuum demonstrates how it can be difficult to make distinctions between technologies, especially Mixed Reality and Augmented Reality [22].

Reality	Augmented Reality	Virtual Reality	Mixed Reality	Augmented Virtuality	Virtuality
The actual world that we experience with all of our senses.	Information and data overlaid on top of the actual world.	A complete digital representation of the actual world.	The introduction of possible elements into an actual world.	The introduction of actual elements into a possible world.	An imaginary world that mostly follows the rules of the actual world.
An actual house.	A realty app provides details of an actual house.	A 3D image of actual furniture. A virtual tour of an actual house.	Simulation of different furniture, virtual or new, in an actual house.	Staging of actual furniture in a new house.	A 3D model for a new house or of new furniture.
Key concept: Physical co-presence of people and objects.	Key concept: Add utility to physical co-presence.	Key concept: Enable perceived presence and full immersion.	Key concept: Adaptation of actual scenarios.	Key concept: Participation in possible scenarios.	Key concept: Vision of a completely different world.
Real			Possible		

Figure 3.2: The reality-virtuality continuum broken down [23].

Figure 3.2 attempts to break down the different degrees of XR. Augmented Reality and Virtual Reality are further explained in the following sections. Some terms, such as Mixed reality and Augmented Reality are closely related. To limit the terminology, the other terms will not be discussed in detail but rather weaved in to either the Augmented Reality or Virtual Reality terms.

3.2 Virtual Reality

In the context of this paper, Virtual Reality is a fully immersive computer-generated virtual environment which the user can in some way interact with [6]. This virtual world is experienced using a head mounted display and most likely some hand held device. The head mounted display consist of one or two screens displaying slightly different angles of an environment through special lenses, thereby deceiving the brain into thinking that it sees something in 3D [24]. This principle can be demonstrated by focusing on something close to your eyes and then alternate between closing one eye. The object you focus on should shift compared to the background. This small difference in what each eye see is part of our depth perception. This can again be demonstrated by the difficulty of trying to catch a ball or judging distance while closing one eye [25].

Figure 3.3: Demonstration of VR using Dimension10 at Alrek Helseklynge. Image provided by Skanska.

3.3 Augmented Reality

AR allow users to see the real world, with virtual objects superimposed upon or composited with their real environment [7]. In an engineering sense, this means the potential to see how something will develop in actual space and geographical location. The most common way of imagining AR is a user experiencing augmented reality through some sort of head mounted see-through display. This is not wrong but AR is not limited to such technologies. A more common form of AR is AR through mobile devices [26]. Pokémon Go is an example of an AR experience using a mobile device. It can be considered the first location-based augmented reality game to reach a mainstream status [27]. Such mainstream breakthroughs help push the technology forwards and creates a public interest in the technology.

Figure 3.4: Pokémon Go allows users to see virtual objects on top of the real world [28].

Figure 3.4 show screenshots of gameplay containing a form of augmented reality. The first panel shows how the player's real-world location is displayed. The second panel shows a Pokémon superimposed into the real world.

3.4 Why use Extended Reality?

A question that needs to be answered is should one consider using XR in the construction industry at all? This section will look at the benefits of using XR instead of conventional tools such as 2D drawings and 3D computer models.

3.4.1 Level of understanding

It has been shown that immersive environments convey information in a more comprehensive manner compared to monitor based or paper based [29].

There are at least three ways an immersive environment can enhance understanding of information: By transfer, by situated learning and by enabling multiple perspectives [30].

Transfer

Transfer is the ability to use knowledge learned in one situation and apply it to another [31]. A common example of transfer in the construction industry is for senior members of a team to be able to identify problems before they occur or knowing how to deal with problems when they occur, mainly because they have experienced something similar on a previous project. A way to implement this concept in a virtual environment would be a virtual case. Even though the person never experiences that exact case in real life, they might be able to draw some parallels and utilize their knowledge. This does not have to be anything more than staying cool in stressing situations or knowing what strategy to use when solving a problem [32].

The term transfer is not to be confused by the term knowledge sharing. Whereas transfer relies on previous personal experiences, knowledge sharing relies on obtaining knowledge from an external source [33]. This external source could be (but is not limited to) other people, articles, news and social media.

Situated learning

"For the things we have to learn before we can do them, we learn by doing them."
– Aristotle

A good way to learn is to try and fail until you do not fail. This can be considered a risky way of thinking if you consider the construction industry in the real world and is not a feasible concept. A better idea is to perform the actions in a life-like, virtual environment and possibly fail. By using authentic contexts and activities coupled with expert mentoring, a gradual increase of skill level is obtained. This is relevant for skilled workers in training and in improving employees' ability to identify and mitigate HSE risks, amongst others. Attensi, a company that will be discussed later, develops games for employers where the employees learn different skills through situated learning. Edgar Dale's cone of experience [34] as shown below in figure 3.5 illustrates the amount of information obtained through different activities. Reading conveys the least amount of information while situated learning provides the most.

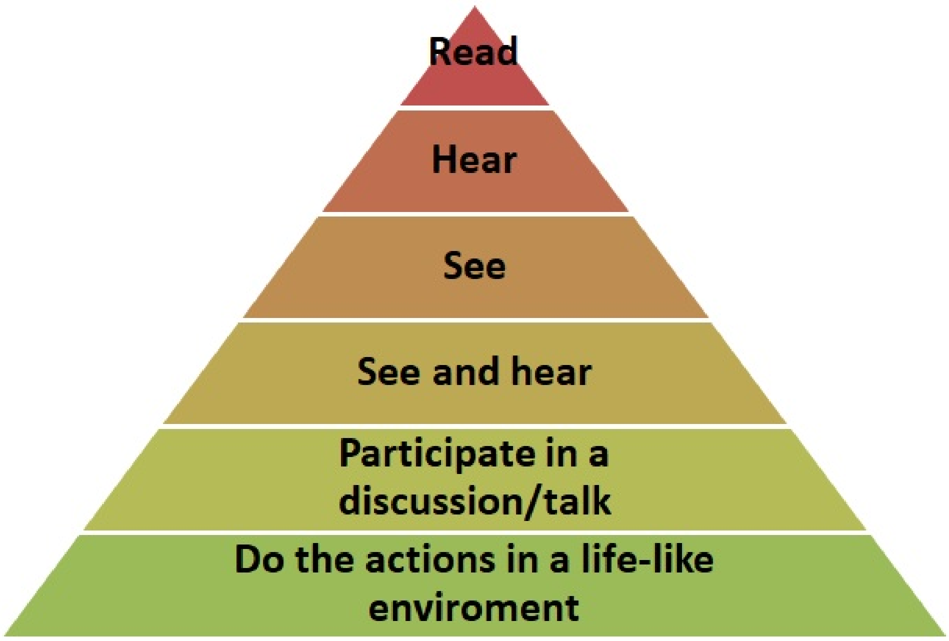
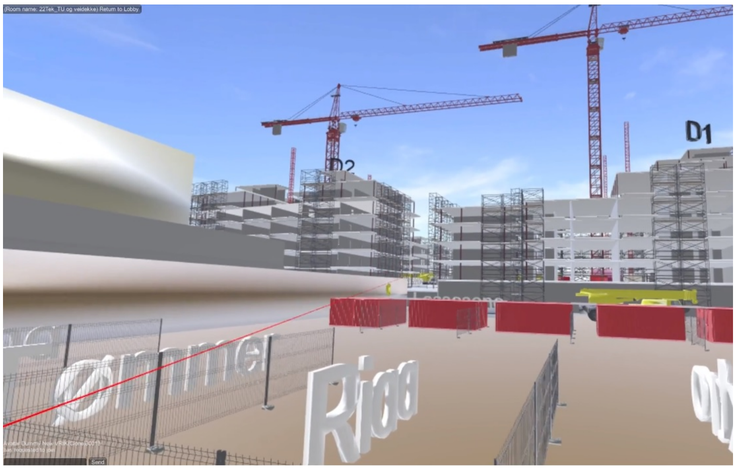


Figure 3.5: Edgar Dale's cone of experience. Illustration created by the author.

Multiple perspectives

The construction process consist of frequent complex problems, be it structural ones or logistical ones. Typical examples are joints or areas containing multiple disciplines, or the planning of a construction site with load zones, placement of cranes and so on. Interpreting 2D drawings or even a 3D model on a screen may not provide enough clarity of the problem. Being able to immerse oneself "in to" the problem and looking at it from any desirable angle, be it exocentric or egocentric, improves understanding of the problem. It has been shown that an immersive virtual environment has a statistically significant advantage over monitor displays when it comes to understanding complex 3D geometry [35].

(a) Exocentric view.



(b) Egocentric view.

Figure 3.6: Screen shots from a video demonstrating the use of Dimension10. Video made by Teknisk Ukeblad. Features Veidekke and Dimension10 [36].

3.4.2 Geometric understanding

The main reason why XR is could be beneficial for the construction industry is the difference in spatial cognition between monitor-based consumption of digital environments and immersive ones [29]. When evaluating a design using XR, realistic proportions are observed but the same can not necessarily be said about 3D designs on 2D display surfaces [37]. The reason for this loss of realism is due to the fact that 3D objects are displayed as 2D objects using projections. A projection is a technique to transform 3D objects to 2D objects [38]. There are essentially two types of projections: Parallel- and perspective projection.

With parallel projection, it is assumed that the "camera" or center of projection is located at an infinite distance from the object [39]. Lines that are parallel in two dimensions remain so in three dimensions. The benefits of using a parallel projection is that dimensions are preserved and parallel lines remain parallel, making such a projection suitable for technical drawings. The drawbacks are that angles are generally not preserved and the fact that it looks unrealistic [40].

Perspective projection assume that the "camera" or viewpoint is near the object [39]. Lines that are parallel in three dimensions are thus not necessarily parallel in two dimensions. The benefit of using a perspective projection is that the size varies inversely with distance, resulting in a realistic look. The drawback is that distance and angles are, in general, not well preserved [40].

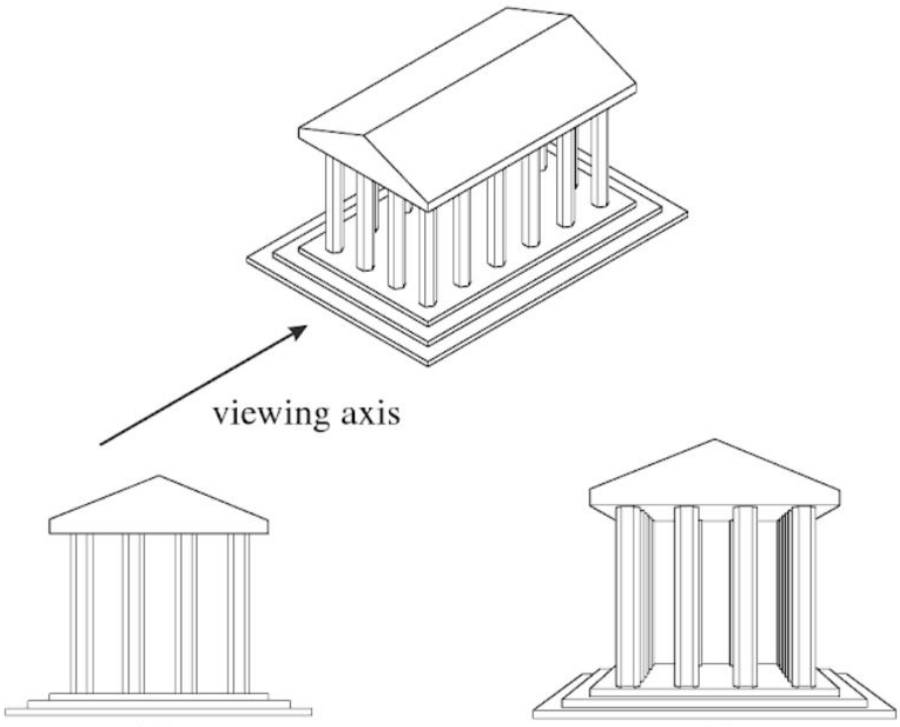


Figure 3.7: Parallel projection (left) and perspective projection (right) [39].

When using XR to evaluate a design, it is possible to obtain the benefits of both types of projections without the drawbacks. A sense of space and realistic design is achieved while preserving dimensions. A design is usually presented using a perspective projection in XR [39], but design properties such as measurements and angles are usually accessible from the model and easily accessed in an immersive environment.

3.5 Hardware

This section will look at XR hardware relevant for the construction industry. The VR hardware mentioned, with the exception of mobile VR devices, was originally developed for gaming but others (not discussed here), have been created focusing on engineering and work applications. It is safe to assume that the market for gaming hardware is larger than the one for engineering. A well known principle in economics is ”economies of scale”. It states that the cost of an item will be reduced as more volume of that item is produced [41]. This explains why the most prominent VR hardware originates from gaming.

It is worth mentioning that other technologies exist, the ones discussed here are they who holds the most promise in the construction industry and are the most popular. They have been selected based on features, availability and mentions in relevant literature.

HTC Vive

The virtual reality headset HTC Vive is made in collaboration between HTC and the video game developer Valve, as both companies have a joint interest in VR. The main head-mounted display (HMD) for the HTC Vive features a 2160 by 1200 resolution display with a 90 Hz refresh rate as well as a 110-degree field of view [42]. Each eye will in effect see a 1080 by 1200 display, making it slightly pixelated. The HMD only weighs around half a kilo making it relatively lightweight. It relies on a relatively powerful PC to run.

Inside the device there are over seventy sensors, including a gyroscope, accelerometer and laser position system sensors. The Vive is not only a headset, but also part of the room scale system, developed by Valve. It consists of two lighthouses at either side of the activity area, usually between 1.5 and 4.5 square meters. The lighthouses emit pulses of structured infra-red laser light inside the activity area that the sensors in the device picks up on. All the sensors help to pinpoint the users position with sub millimetre precision [53]. The Vive kit costs about 7 000 NOK, making it a high-end consumer VR technology. it is worth mentioning that a pro edition also exists. The biggest difference here is that the pro version has better resolution (2880 by 1600) and can be used wirelessly. This kit costs about 15 000 NOK.

Figure 3.8: HTC Vive Pro accompanied by lighthouses [43].

Oculus Rift

Oculus was the original company to revive the interest for virtual reality back in 2012. It started with a Kickstarter campaign for a prototype VR headset [44]. The first initial prototypes were the first attempt to bring a VR headset to the average consumer, but were lacking in features. A later updated version brought along improved specifications, like increased refresh rate and resolution, as well as head-tracking by using an IR camera [45]. The First consumer version to be released was in 2016 and have many of the same specifications as the Vive, like the resolution and refresh rate, just without the hand controllers and room scale [46]. A hand controller system, Oculus Touch, has later been released as an alternative to Vive's room scale system [47]. A kit consisting of both the HMD and the Oculus Touch costs about 5 000 NOK, making it a high-end consumer VR technology. Like the HTC Vive, it relies on a relatively powerful PC to run.

Figure 3.9: Oculus Rift accompanied by Oculus Touch [48].

Microsoft Hololens

Microsoft Hololens is a AR device and arguably, the only viable option at the current time for structural engineering applications [49]. It has 2-3 hours of active battery life and two HD 16:9 light engines that project light through holographic lenses leading to a total resolution of 2.3 million light points. High resolution spatially located 3D content is generated by this system in cooperation with the rest of the hardware. It is a stand-alone product, i.e. not tethered to a computing device. The HoloLens also includes an Inertial Measurement Unit, four environment-processing cameras, a RGB camera, and one depth camera to map its surroundings and allow interaction between the real and virtual world while tracking the device's position. Other features include four microphones, gaze tracking, gesture input, spatial sound and voice support [49].

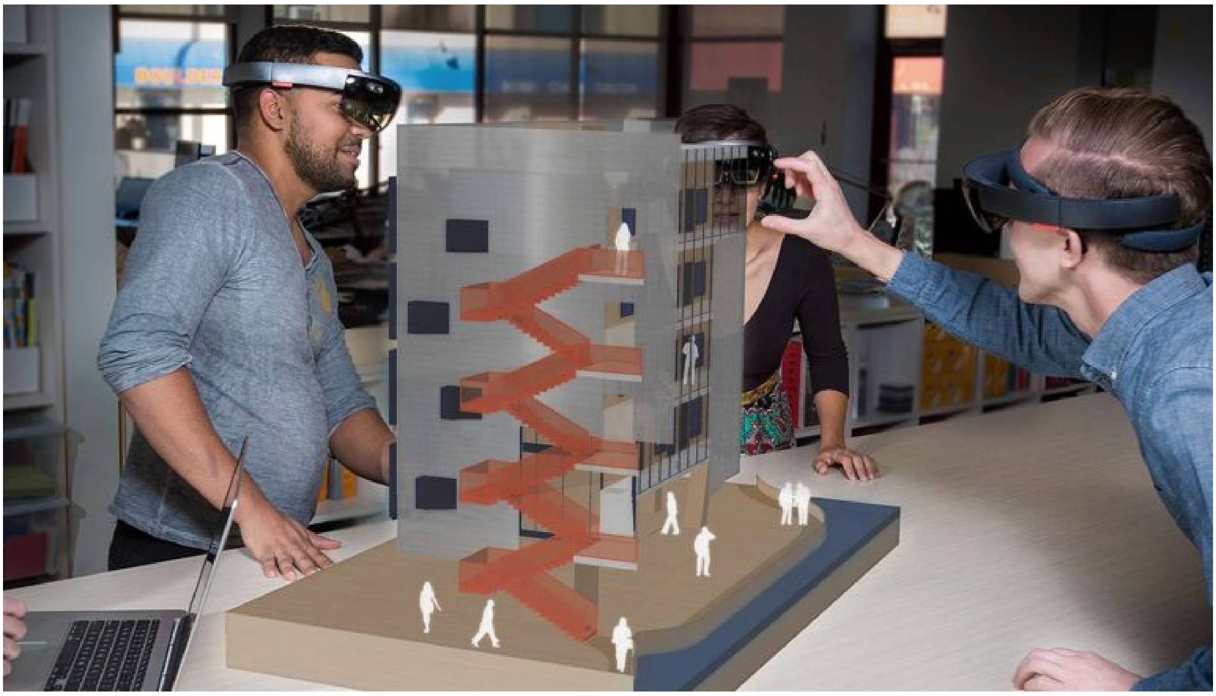


Figure 3.10: Illustration of Hololenses being used for structural work [50].

Hololens 2 has just been announced (Feb. 2019) and is said to be launched this year at a price of about 30 000 NOK. According to Microsoft, the field of view has been doubled while maintaining the pixel density. This has been reported as one of the weaknesses of the original Hololens, a narrow field of view. A big difference in the two models seems to be who Microsoft considers as a buyer. Whereas the original Hololens targeted everyone, the new Hololens 2 seems to target industries and businesses [51], [52].

DAQRI

DAQRI is a developer of industrial AR solutions. DAQRI Smart Glasses is a kit consisting of wearable smart glasses, and a processing unit with plenty of computing power and supported connectivity such as USB 3.0 and bluetooth [53]. DAQRI is best known for their AR smart helmet but has shifted their focus to smart glasses, removing information about the smart helmet on their website. [54]. This can be interpreted as broadening their client base.

The glasses are coupled with DAQRI's own software: DAQRI Worksense. It is advertised with the key words "show, tag, model, scan, guide" [53]. Show refers to the possibility of shared view where someone on a computer can be invited to access the camera feed from the glasses. Tag refers to the possibility of tagging objects either on a computer or on-site using the glasses. The tag is updated so that it is accessible from both computer and on site. Model refers to when the model is placed on top in its actual geographical location. Scan refers to the possibility of scanning an environment and creating a digital model of it. Guide refers to the possibility of making tutorials or manuals for different procedures and operations, that are accessible from the AR overlay.

Still in a beta-testing (development) phase, the glasses seem to hold great promise for the construction industry once fully released.

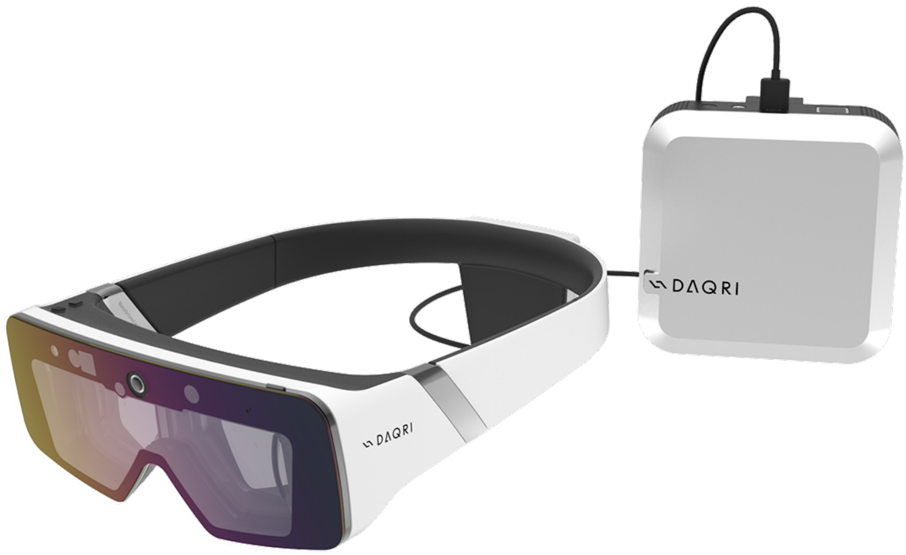


Figure 3.11: DAQRI Smart Glasses [55].

Mobile VR

Unlike the previously mentioned hardware, devices such as Samsung Gear VR, Google Daydream and Google Cardboard are not dedicated VR devices. They are essentially a plastic or cardboard headgear with optics, relying on a mobile phone to provide a screen. The difference between different mobile VR headgear is generally about compatibility, ergonomics and build quality. Such VR solutions provides the possibility of VR at much lower prices. They are also more portable, only requiring a mobile phone instead of a computer [56].

A drawback is lower quality motion tracking of both the headset and the controller (if controller input is supported). This is due to the fact that HMD like Oculus Rift and HTC Vive have advanced tracking hardware as mentioned earlier, while mobile VR headgear relies on the phone's built-in sensors and gyroscopes. Another drawback is the potential for a low frame rate. To provide an experience that is perceived as "smooth" and comfortable for the user, a frame rate of 90Hz is recommended [57]. A mobile phone can struggle to provide such a frame rate, and the graphics may suffer as a trade-off for higher frame rate. In context of the construction industry, the possibility of moving around in the virtual environment offers a considerable advantage. Not all mobile VR solutions provide a controller for moving around. Mobile VR also only support three degrees of freedom (roll, pitch, yaw) [58].

Figure 3.12: Rolling, pitching and yawing [58].

Figure 3.12: Roll is where the head pivots side to side (i.e. when peeking around a corner). Pitch is where the head tilts along a vertical axis (i.e. when looking up or down). Yaw is where the head swivels along a horizontal axis (i.e. when looking left or right).

Applications of VR in the construction industry will be revealed in chapter 4 and 5. From the information presented in those chapters, it is clear that in terms of the construction industry, dedicated VR devices are arguably preferable. The need for mobility is low while the need for high quality graphics and motion tracking are high.

Mobile AR

While the design phase in a construction project is largely digitized and increasingly integrated around BIM, the degree of digitalization on the construction site during the build process is still low [59]. For a complete digitalization of the construction industry, structured information models would need to be available on the construction site. A step on the way could be to utilize mobile phones and tablets (that are already widely used) to introduce AR. Mobile phones and tablets can provide AR, as shown in section 3.3 with Pokémon Go. Mobile AR refers to using mobile, hand-held devices such as mobile phones and tablets to create an AR experience.

In a construction context, it has been shown that AR can improve the understandability and usability of project documentation in the visualisation of preliminary studies and in monitoring the construction process [59].

The limitations of mobile AR is: The virtual model is not completely aligned with the surrounding area, the construction site fence and the other elements located between the observation point and the building, obscuring the model, and small size and low resolution of the model [8], [59].

Considering the improvements mobile based AR offers as well as the drawbacks, it is clear that it holds some promise in applications such as early visualization and supervision of a construction project. Applications will be discussed later in chapter 4 and 5 but it becomes clear that the level of precision required by AR devices during construction can in some cases not be provided by mobile AR. Mobile AR also suffer from the same drawbacks as mobile VR in terms of degrees of freedom and graphics. In the construction phase, a dedicated AR device, such as Microsoft Hololens, is therefore preferable.

3.6 Software

This section will look at the most popular software for XR applications in the construction industry. It is worth mentioning that these softwares are developed by companies for economic reasons. This thesis will not compare commercial softwares to determine who is best but rather briefly discuss the largest commercial softwares and identify suitable areas of use. It is assumed that the reader has knowledge about BIM and CAD software in general and is acquainted with the most popular programs.

Revizto

"Revizto is a real-time issue tracking software for Architecture, Engineering and Construction with a focus on collaboration and BIM project coordination" [60]. It is a software that allows all disciplines of a construction project to work together on the same model, while identifying and correcting errors in real-time. In regards to VR, it converts BIM and CAD models created in software such as Trimble SketchUp, Autodesk Revit and Autodesk AutoCAD to virtual, navigable environments accessible with Oculus and HTC Vive [61]. It also allows for facility managers to use VR as a tool in a building's operations phase [62]. In general, Revizto is a software that focuses on an easy transition from a computer model to the virtual world as well as issue tracking. An issue can be assigned in 2D, 3D, clash detection testing or a VR walk-through and responsibility, deadline and priority can be assigned [63].

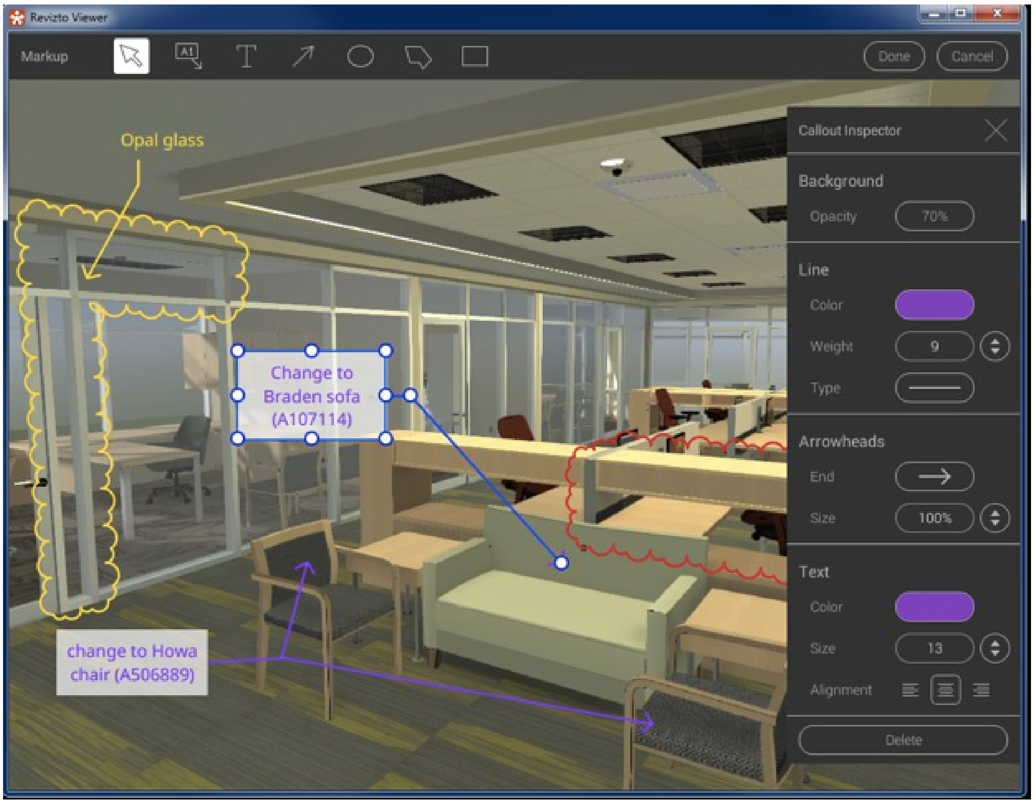


Figure 3.13: Illustration of the workings of Grit Revizto [64].

Attensi

Attensi provides solutions for game based learning. An interactive game is created by Attensi with a setting from real-life [65]. In the construction industry examples of use are HSE training and high-risk task simulation. A gamified simulation offers a more fun and interactive way of learning compared to traditional video and reading as well as a higher level of learning compared to for example a video, as discussed in section 3.4. Another aspect of gaming is the fact that you can get scores and “rewards”, which is proven to be a great way to motivate people [66].

Figure 3.14: Screenshot from a video illustrating the workings of a game made by Attensi. The game in the figure is made for the training of people working on a ship [67].

Dimension10

Dimension10 is comparable to Revizto in the way that the software focuses on an easy transition from BIM to VR and cloud storage. It supports software from the most common BIM software developers such as Autodesk and Solidworks [68]. It is also possible to have multiple participants in a single virtual space, as well as scaling down the VR model from real size, as shown in figure 3.6 in section 3.4 [36]. This makes it possible to have virtual planning meetings, site plan meetings, amongst others. It allows the user to see all layers that exists in the original BIM model and to turn them on and off as it suits the user. Several interview subjects reported that this feature is especially useful. A drawback is that the experience in VR is most suitable for AEC professionals due to the fact that it does not provide life-like graphics. The software focuses on functionality over design. This problem will be further discussed in chapter 4. Dimension10 is used to some degree by, but not necessarily limited to, Skanska and Veidekke.

NOTE: Dimension10 has been used by the author. Some statements in this section are not referenced but are based on personal experience.

Grit Virtual

Grit Virtual is a "crowdsourced" construction scheduling program. Instead of a traditional "top-down" command and control approach to scheduling, it relies on feedback from the users, mainly the general contractors. At the start of a project, users can walk through the project in VR and identify the resources and tasks they need to complete the project on time and within budget. The software figures out the best way to schedule while the users feed it updates and completed tasks [69].

Grit Virtual implements all levels of planning into one project, from the master schedule to the daily tasks. Instead of looking through a typical Gantt chart, one can instead search for tasks relevant to one's discipline. Another feature is that the programme will automatically try to compensate for delays, either by moving activities and manpower around or by looking at potential advantages that can be gained by this delay [70]. It supports both VR- and AR visualization on devices such as Oculus Rift and Microsoft Hololens, as well as traditional visualization on pc and tablets [71]. It also utilizes cloud storage, meaning that you can access the newest schedule at any time on any supported device.

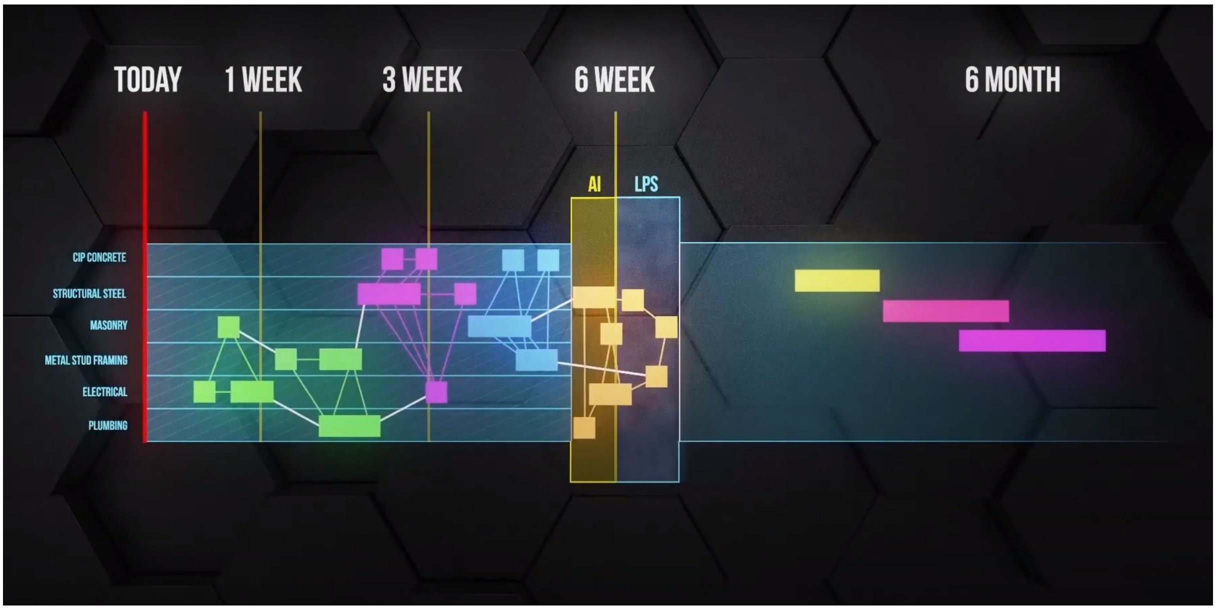


Figure 3.15: Screenshot from a video illustrating the workings of Grit Virtual [72].

Figure 3.15 illustrates how Grit Virtual treats activities depending on how far from today it is. From 6 months to 6 weeks it is treated as a typical Gantt chart. When the activity is to be carried out in six weeks, the program utilizes Last Planner System (LPS) principles to break up the activities in to discrete work packages. It then simulates all possible construction sequences to find the optimal one [72].

Unity

Unity is a game engine but is used for many other applications due to it being open sourced. Unlike the previously mentioned softwares, Unity is not a "off the shelf" product; it is a development tool and can be whatever you want it to be. Since Unity originally was developed as a game engine, it has the potential for the most life like simulations of any program, since it already includes the potential for life-like graphics and an advanced physics engine. Skanska uses Unity when high quality graphics are required, for instance when creating virtual mock-ups of hotel rooms and such. Unity does require a bit more from the people developing the VR solution compared to for example Dimension10, which is essentially plug-and-play. The benefit is more freedom to develop whatever you need and the potential for higher quality visual output.

Unity will soon allow users to import Revit models and convert it into a VR model without losing the properties of the components in the .rvt file [73]. This feature is expected to be completed by fall 2019.

Figure 3.16: Screenshot from a video illustrating the potential of Unity. The figure shows the user in VR being able to directly access information about items in the model [74].

NOTE: Unity has been used by several interview subjects. Some statements in this section are not referenced but are based on their personal experiences.

Trimble SiteVision

Trimble SiteVision differs from the other softwares listed because instead of a fully immersive VR experience, the user experiences AR. Information is added on top of the real world to enable users to see what a construction site will look like in the future or what is beneath the ground. This requires Trimble's own GNSS (Global Navigation Satelite System) hardware since this technology relies on the user's precise location. The hardware is linked to the users own phone or tablet [75]. Applications are for ex: Visualization of subsurface utilities, visualization of landscape, visualization of rework or add-ons to an existing structure and so on. This technology is still in a testing phase and has only been used on pilot projects but appears to have high potential if the final product is as good as advertised.

Figure 3.17: Demonstration of Trimble SiteVision on a mobile device with the GNSS device. Picture provided by Skanska.

3.6.1 Summary - Table

Software	Supported Formats	Suported Hardware	Focus Areas
Revizto	Revit Navisworks Navisworks ArchiCAD AutoCAD Civil 3D Solibri Tekla SketchUp Rhinoceros	HTC Vive, Oculus Rift	Easy transition to VR and issue tracking
Grit Virtual	60 + formats (essentially all)*	Oculus Go, Oculus Rift, HTC Vive, Microsoft Hololens, PC, Tablet, Mobile	Scheduling
Attensi			Training (end-users and skilled workers)
Dimension10			Easy transition to VR and virtual meetings
Trimble SiteVision		Tablet or mobile connected with Trimble's own GNSS receiver.	On-site quality assurance
Unity	Any platform**	Any hardware**	Freedom to create what you desire with the potential of life like graphics

*Autodesk Forge has been used for the model view feature. It supports all major CAD formats, not only Autodesk formats [76].

**Unity has a freedom of development that allows desired featured to be added as they are needed.

The author was unable to firmly establish the information lacking in blank cells. Some information is presented in the previous sections.

Chapter 4

Interviews

This chapter will present the findings from the interviews conducted. It will look at each interview group individually before comparing all findings. Findings from each interview group will be presented as in a SWOT analysis, placing statements in the appropriate category. Users of a SWOT analysis often ask and answer questions to generate meaningful information for each category to make the tool useful and identify their competitive advantage. SWOT has been described as the tried-and-true tool of strategic analysis [77] and have therefore been assessed as an appropriate way of structuring the findings from the interviews. Where multiple people have been interviewed, recurring opinions and views have been used in the SWOT analysis while individual views have been discussed where suitable.

It is important to take note of the different backgrounds of the interview subjects. They will have different experience and competence on the subject. Some develop XR solutions while some have used it on a project.

4.1 Alrek Helseklynge

Technology: HTC Vive Pro with Dimension10
Location: Bergen
Client: University of Bergen (UiB)
Contract sum: 440 000 000 NOK
Construction phase during interviews: Ground works/early construction phase

Alrek Helseklynge is a turnkey project carried out by Skanska. It will be a state-of-the-art medical research- and educational cluster. When finished, there will be 24 000 sq.m. of lecture rooms, offices and meeting rooms for all health care students and faculty at UiB.

Figure 4.1: A rendering of Alrek Helseklynge when finished. Picture provided by Skanska.

At the time of the interviews, VR had used for about 6 weeks at the project. A thorough design process had been carried out by UiB so that when Skanska entered the project, practically all design decisions had been made. In the contract it was stated that the construction should be as digital as possible. For this reason, it can be said that the contract form encourages the use of VR. Five project team members were interviewed.

Figure 4.2: The construction site in Spring 2019. Picture provided by Skanska.

4.1.1 Areas of Use

At the time of the interviews, the project was in an early construction phase and the VR setup had only been available for 6 weeks. For this reason, areas of use were somewhat limited. The areas of use revolved around pure visualization of the finished project. All interview subjects stated that VR had been used to get a feeling of a room while some also said it had been used to test the usability of a room. This is where VR excels compared to a regular BIM model; it allows the user to experience a sense of space.

Because the project was in such an early phase, VR had not been used to test the feasibility of a design, but several interview subjects believed that this would be an application as soon as structural work would begin.

4.1.2 Strengths

Something that was not revealed by the literature review is the fact that being an early adopter of XR technology demonstrates to the public that as a company, Skanska has ambitions about being at the forefront of the industry. It demonstrates a willingness to test new solutions and a desire to optimize the construction process. This functions as a selling point when attempting to acquire new projects and provides experience in terms of the company CV. Using the project in Bergen as an example, it was stated in the contract that the construction process should be as digital as possible. There are already examples of contracts requiring VR, something that is likely to become even more common in the future. Companies should prepare for such an eventuality.

Another strength of VR that will be discussed further was discovered in the interviews. VR provides an excellent platform to bridge the gap between AEC professionals and clients or end-users. The importance of clear communication and a common understanding of the project cannot be stressed enough [2], [78]. At the Alrek project, all interview subjects reported that VR was a great tool to communicate with end-users and maintain a good relationship. It allows for end-users to be involved in the process earlier that in a typical construction project.

4.1.3 Weaknesses

When asked about potential problems and difficulties regarding VR, all interview subjects recognized that it is not enough to simply provide a VR setup. To ensure that people actually use it, interest must be maintained and a continuous benefit must be demonstrated. This interest often requires a highly enthusiastic team member that pushes for the use of VR. The technology does not have the maturity and the same level of recognized benefits as for example BIM, so without continuous use and one or several people to inspire use, it is likely that VR will not be fully embraced.

4.1.4 Opportunities

1. Being an early implementer of the technology can put Skanska in a leading position in the marked, in terms of XR. It presents an opportunity to gain specialized knowledge in a field that has the possibility of becoming an industry standard.

2. The technology shows great promise in terms of decision making for clients and end-users. In this project, VR was not used for decision making but interview subjects clearly recognized the potential for such a use. Instead of making mock-ups, a project owner can modify and determine design in a virtual setting, which could potentially offer huge savings in terms of time and money.

3. VR holds great promise for end-user understanding, planning and checking the feasibility of a solution, according to the interview subjects. The improved understanding VR offers, provides a greater understanding for all participants, simplifying their role in the project, be it making plans for construction or reviewing a specific technical problem.

4. AR seems to be very beneficial for skilled workers but the technology does not seem to be at a level of maturity where it offers any real benefit to equip all skilled workers with a HMD. The potential ways to use it could be accessing relevant drawings and models on site and having the model as an overlay over the built, or soon to be built structure. The benefits of these applications will be discussed later, in chapter 5.

4.1.5 Threats

Opinions about potential threats were somewhat scattered but revolved around a hesitation of using the technology. The interview subjects identified three potential threats: Unsuccessful implementation due to a lack of interest, a hesitation to use VR due to low user friendliness, and the need for a clear strategy for the use of VR on the specific project.

1. Unsuccessful implementation due to a lack of interest: The only measure to increase and maintain interest was as already mentioned, a highly enthusiastic team member.

2. Hesitation to use VR due to low user friendliness: Low user friendliness needs to be addressed by the software developers, either external ones or developers in Skanska using Unity. Further research in to this should be made and a feedback system should be established to ensure constant improvement by using end-user experiences.

3. The need for clear strategy for the use of VR on the specific project: At Alrek Helseklynge, the VR strategy was mainly to use it were it could be used. As the technology matures and more users get hands on experience with it, a proper strategy should be developed for the use of VR on each specific project. This could be done by having the VR team in Skanska making templates stating a suggested strategy for the use of VR, depending on the level of implementation/use. Is the VR setup just for visualization of the model? Does it support multiple participants in a single virtual space? Is the schedule linked to the VR model? These templates can then be modified as the project team see fit. The point of such a strategy is to ensure that people use it and are aware of the possibilities the technology offers. Without such a strategy, it is possible that the use of VR on the project will dwindle to just a gimmick.

4.2 BIM/VDC Department, Skanska Norway

Where the inteviews with the project team at Alrek Helseklynge provided a project team point of view, the interviews with the BIM/VDC department at Skanska provided a point of view from developers, amongst others. This provided the opportunity to ask about specific problems reported by users and what the developers do to address this. Four people were interviewed: A full-time XR developer, a BIM advisor, a project manager and a project developer. Due to the different backgrounds, the answers and opinions were more individual and scattered than the ones at Alrek Helseklynge.

4.2.1 Areas of use

All interview subjects reported that they had used it to get a sense of space or to show someone a design. This has already been discussed to some degree and will be further discussed in section 5.1.1. Other areas of use revolved around end-user decision making.

An area of use that emerged that has not been discussed is to use VR to create a virtual mock-up of a room (Arnulf Gausereide, Appendix). This was done in the tendering of a hotel.

4.2.2 Strengths

The strengths of VR that has not already been identified involves the creation of virtual mock-ups. By creating a virtual mock-up, money is saved and it is much easier to make design adjustments, following the customers feedback. Another benefit is the "green" aspect of it; materials used to make a mock-up are saved. The mock-up will most likely end up as waste anyway, so there are two ways it is beneficial.

4.2.3 Weaknesses

In a meeting, VR is most commonly used by one person at a time. It is common to have a regular screen that displays the view of the person using VR so that other participants can see what is being discussed, as seen in figure 3.3. An interview subject (Antje, Wigland, Appendix) reported that this can result in a divided discussion because the people watching the screen does not experience the immersive nature of VR. This could be solved by using software that supports multiple users (like Dimension10) or create that functionality in Unity.

4.2.4 Opportunities

AR technology was mentioned by several interview subjects as a technology that holds great promise in the near future. Promising areas of use was identified as AR for physical work applications in the construction phase of a project. Physical work applications refer to tasks carried out by skilled workers on the construction site. An example given was to use AR when placing rebars. Today this work relies on regular drawings or a tablet offering the possibility of an interactive 3D model. AR could further increase the understanding and thereby the efficiency of such work.

AR was also mentioned as especially useful for operating and maintaining a building. While this is not a construction industry application, it holds great promise. This would be done by handing over a BIM model to maintenance personnel when the building is complete. If they need to locate special installations, they can easily do so using an AR device that displays the BIM model as a 1:1 overlay over the actual building. Instead of having to interpret 2D drawings, they can simply walk around in the building and locate desired installations.

With project owners requiring a higher degree of digitalization, staying ahead of the digitalization curve is obviously beneficial. The Norwegian Directorate of Public Construction and Property (Statsbygg) is a government agency that manages central parts of the real estate portfolio of the Government of Norway and develops some of the largest projects in Norway [79]. They have required that all design should be done in BIM and that the construction sites should be paper free on their projects [80]. Assuming that other project developers follow and that new requirements are introduced over time, it is not impossible that requirements of both a VR model at the start of the project and an AR model at handover will be the industry standard in the future.

4.2.5 Threats

To ensure the commitment and focus on XR technologies by Skanska, the benefits the technology offers must be quantitatively documented. Stating that the technology may be beneficial is not enough. At some point, the return and profitability must be investigated and confirmed. At the current time, such an endeavour would provide unsatisfactory results due to the moderate maturity of the technology (which was revealed through the literature review and the interviews).

4.3 Niras

Niras is a Danish consulting company specializing in engineering. Even though the offices in Stavanger are relatively small, they are known for their BIM/VDC competence and being early implementers of new technology. A single group interview was carried out with two interview subjects.

Two projects were discussed in detail: A chicken factory and a trial. The chicken factory was a typical construction project where Niras was hired as BIM managers. The trial was between a contractor, a consulting company and the project owner in the building of a dam. Niras was hired by the contractor to illustrate the complexity of the placement of rebars in the dam which was curved around two axes. Already quite complex, the amount of steel reinforcement was increased during the construction phase, further increasing the complexity of the project. This increased complexity resulted in the contractor having to work in shifts, both day and night to meet already agreed upon deadlines. The trial revolved around different points but mainly around who should pay for the costs associated to the new, more complex design.

4.3.1 Areas of Use

The interviews with Niras revealed two main areas of use: Visualization of design, and end-user involvement.

Visualization of design: In the chicken factory project, a VR experience was created to illustrate the dimensions of the dig site. This clearly conveyed Niras' concern about the difficulty accessing the dig site.

Niras' task in the trial revolved completely around visualization. The problem the contractor faced in the trial was to illustrate to non-AEC professionals the complexity of the design. By allowing judges and lawyers to "step in to" the dam in VR, a new, clear point of view was obtained. The rebars of a section of the dam was also extracted. A VR experience was created to allow people to experience the complexity of the rebar design as a standalone feature. This clearly conveys the complexity of the work by removing any non-essential features. An important point throughout the process was to illustrate the case objectively and let the complexity speak for itself.

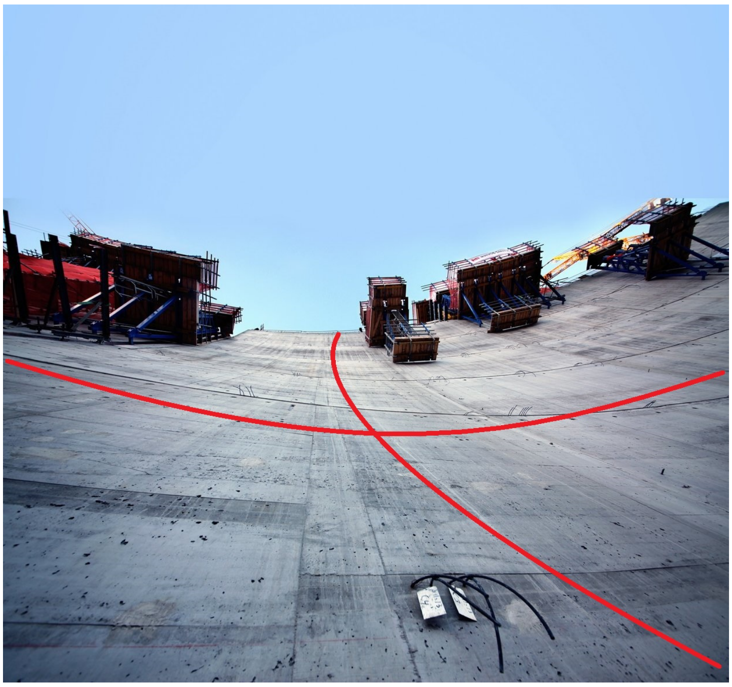


Figure 4.3: The dam in question [81].

Figure 4.3 shows the dam in question. The red lines are added by the author to illustrate the double curvature.

End-user involvement: The workers at the factory was given the opportunity to test their work stations before construction began. This ensures that the finished design is something that enable the workers to do their work effectively in a comfortable setting. The testing involved checking the space requirements and lighting conditions.

In terms of space requirements, Niras modelled a pallet truck that with visual and auditory effects (a chicken that chuckled and jumped up and down) let the user know if it collided. It may sound a bit simple and silly but it worked. It also demonstrates the possibilities of the gaming-engine Unity when connected with BIM-software.

4.3.2 Strengths

The interview subjects at Niras clearly recognize the strength of VR to convey information to non-AEC professionals. Practically all interview subjects recognized this as the biggest strength of VR and is supported by the literature [82], [83]. VR (with Unity) offers the possibility of creating whatever the client desires. This provides all new possibilities in terms of visualization and design testing.

4.3.3 Weaknesses

1. Software updates: It was reported that constant software updates are a weakness. If you prepare a VR demonstration, it might not work the next day due to a new update. If the people you are presenting to already are a bit sceptical about VR, such issues about the stability of the technology does not exactly help to convince already sceptical people.

2. User scrutiny:It was reported that non-EAC professionals have a tendency to make criticisms about non-relevant factors when presented with a VR model. This does not have anything to do with the VR technology but more about the user. This issue will be further investigated in section 5.1.1. It appears that the more understandable VR model (compared to a BIM model on a computer screen) makes clients more aware of the design and they therefore start making comments about the design not really asked for. An example could be having someone looking at the placement and size of a window in VR. Instead of focusing on the window, the user starts to make comments about the placement of shelves and the colours on the wall. A solution proposed by Niras was to focus on the issue in question and make the rest of the model insignificant. This could be done by using grey on the parts of the model that are insignificant or simply remove them.

4.3.4 Opportunities

1. 5D+VR: Much like XR, 5D BIM is getting some traction in the construction industry [84]. 5D BIM is a BIM model that incorporates scheduling and cost information [85]. A further development of these technologies would be to combine them to create a 5D model that can be experienced in VR. Besides the visualization aspect one could gain benefits from letting the project owner interact with the model and see how it would affect time and cost. A proof of concept has been developed by Niras.

2. Virtual meetings: A construction project usually consists of a lot of meetings. These meetings may be limited to construction team members or include the project owner and external consultants. A typical problem is that different people have different drawings and models, different versions of drawings and models or are completely lacking any information. By having meetings in a virtual environment, you ensure that all participants make decisions based on the same information. Participants are not required to be at the same location either, allowing for more flexibility in terms of scheduling for meetings.

3. AR: Everyone on a project having an AR device linked to a cloud-stored BIM model presents the possibility of several benefits. For a skilled worker it means instant access to the newest drawing for the relevant task. For a project member it could be used for verification of progress. This would be done by comparing the built structure to an overlay that shows what is planned at that specific time (AR+4D BIM).

4. High risk tasks: Tasks that have a high probability of injury to personnel, or tasks that only have one attempt to be carried out correctly could benefit from VR. These tasks could be simulated in a virtual environment that is as realistic as possible. This prepares involved personnel and pinpoints potential problems that may arise when executing the actual task.

4.3.5 Threats

A threat to all companies is having to play catch up when new technology is introduced. According to Niras, the rate of which new technology is introduced right now is much higher that a couple of years ago. It is hard to predict which technologies that will become the industry standard but refusing to adapt and implement new technologies is a danger to all companies.

Several interview subjects, including Niras, have reported that a sort of technology barrier exists with regards to VR. This is especially valid for people that have been in the industry for some time. A danger is to implement the technology without proper training, thereby alienating people that struggle with the technology. The people that have been in the industry the longest arguably have the most knowledge and experience and it should therefore be ensured that they are comfortable with the technology so that they can properly impart their knowledge to younger professionals.

4.4 Results from interviews

This section will compare results from the interviews, and identify recurring opinions and points that should be further discussed. Only a few interview subjects had any experience with AR at all. Even fewer had experience with dedicated AR devices, such as Microsoft Hololens. It quickly became clear that most questions would revolve around VR with the exception of question 5: "In which areas do you believe XR has the most potential? What technology is best utilized by who?"

4.4.1 Areas of use

Areas of use reported by the interview subjects were very similar. They include visualization, achieving a sense of space and checking the usability of a room. The benefits of immersion also enabled designers to involve end-users in the design process to a higher degree than compared to conventional means of presentation. A deeper investigation in to areas of use will be carried out in chapter 5.

4.4.2 Problems when implementing XR

The interview subjects identified what they believed to be critical factors to control if VR is to be implemented successfully (question 4 in the interview questionnaire). Figure 4.4 shows the problems of implementing VR according to the interview subjects, as a radar chart. The number (y-axis) represents how many out of the eleven people interviewed that gave an answer suitable to each category. Some interview subjects identified several problems while some were unable to identify any. An attempt has been made by the author to make categories of potential problems that accommodate several answers while keeping the problems clearly separable.

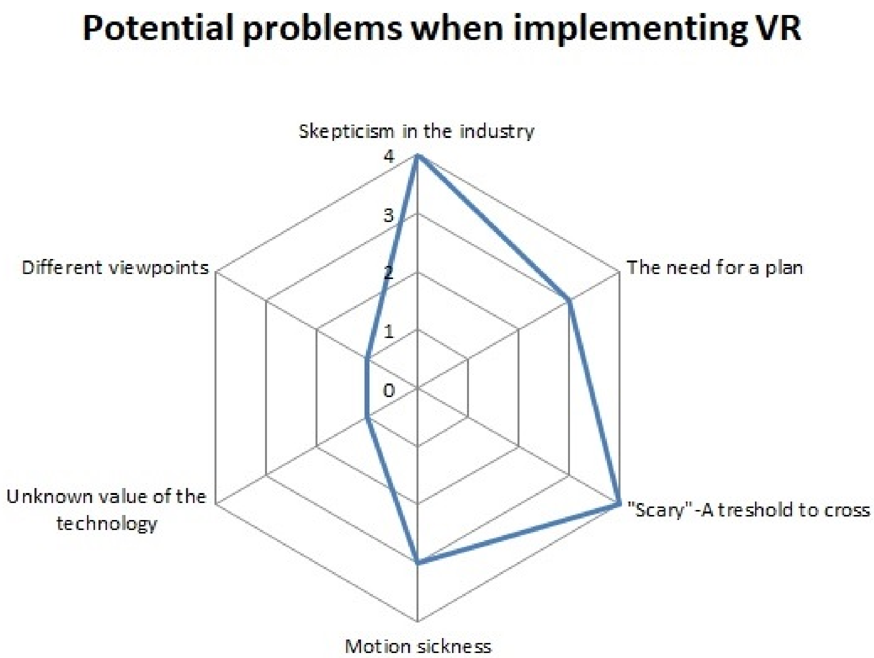


Figure 4.4: Graphic illustration of reported problems of implementation.

The results clearly show four potential problems that needs to be addressed to ensure a successful implementation of VR:

1. Scepticism in the industry: The industry has been fine without VR. Why should they start using it now? This scepticism most likely revolves around questions about unknown value of the technology and hesitation about learning something new. Several of the interview subjects agreed when asked about the similarity between the introduction of BIM years ago and the introduction of VR now. The advantages may seem unclear to some but will probably become clear after some use.

2. The need for a plan: Several interview subjects with varying backgrounds reported that to properly utilize the technology at a project, a proper plan must be in place. Such a plan may be separated from or included in the BIM strategy of a project. Drawing parallels from a typical BIM strategy, key points such as expected areas of use, who should use it, who is responsible for updating the model and how detailed it should be are examples of key points that should be addressed [86].

3. "Scary" - A threshold to cross: A typical problem with new technology is the scepticism and hesitation amongst professionals that have their own preferred method and technology [87]. Depending on the person, such new technology may be considered a threat to their profession and a sceptic view on the technology is understandable. Much like the first problem ("scepticism in the industry"), it is reasonable to think that the acceptance of XR technologies will improve as time goes by and more people actually get to use it. Figure 4.5 shows the BIM awareness and usage over time in the UK construction industry [88]. If XR technologies will have the same rate of adoption is unclear but it is reasonable to believe it will follow a similar pattern.

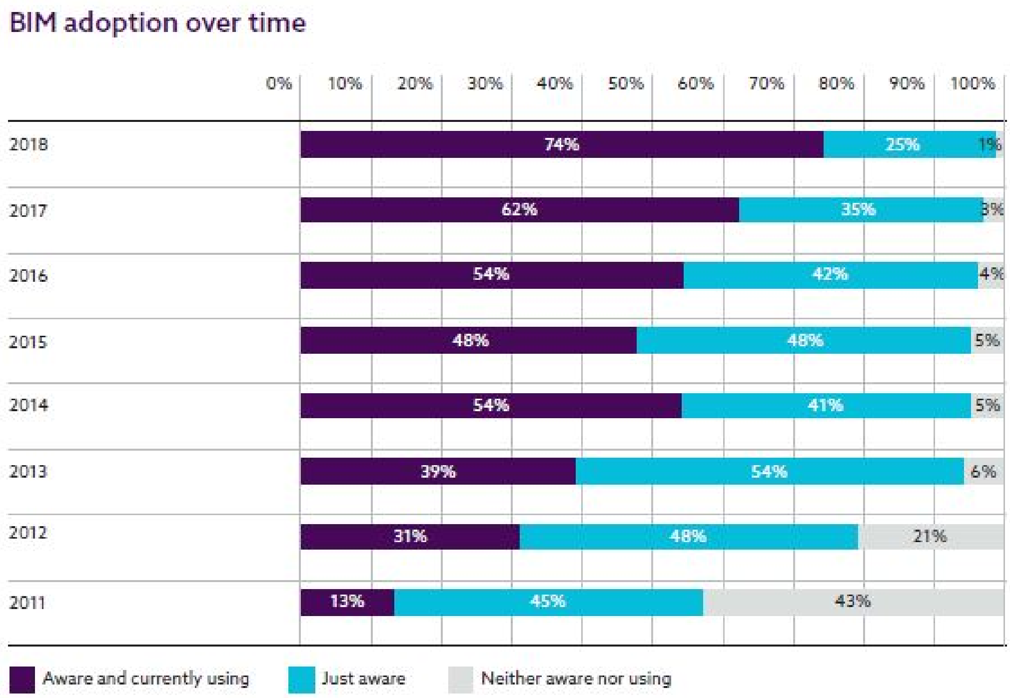


Figure 4.5: The figure shows the use of BIM over time in the UK construction industry [88].

4. Motion sickness: Two interview subjects reported that they had experienced motion sickness to some degree after using VR. The VR-developer interviewed (Sofie Bergqvist, Appendix) stated that avoiding motion sickness is a key point when developing XR solutions. If a user has a bad time when using XR for the first time, it is safe to assume that the user will look at the technology in a more negative way, maybe to the point where they refuse to use it.

   Typical problems are vertical mismatch between the user and the view in VR (not relevant in AR), a delay between a user's head motion and the perceived head turn in XR and low frame rate [89]. All these problems need to be addressed even if the user is unable to move in VR. If motion is included, even more potential problems arise.

The last two categories (”Different viewpoints” and ”Unknown value of the technology”) only had one answer each and have been discussed to some degree earlier.

”Different viewpoints” means that a person immersed in a virtual environment has a different viewpoint than people outside said environment. This problem can for example be expected in a meeting where only one person is using VR. One interview subject reported that she had experienced this, and that the result was a non-coherent discussion, essentially two different discussions.

”Unknown value of the technology” implies that a technology will not be used unless the value of it can be documented.

4.4.3 The potential of XR

The interview attempted to identify the most promising areas of use, both at the current state of the technology and in the near future (question 5 in the interview questionnaire). From figure 4.6 it is clear that the interview subjects identified several potential areas of use. The number (y-axis) represents how many out of the eleven people interviewed that gave an answer suitable to each category. Some interview subjects identified several potential areas of use while some were unable to identify any. By reviewing the answers given (in the Appendix) it is clear that the answers are somewhat unique but often concern the same area of use. An attempt has been made by the author to make categories of areas of use that accommodate several answers while keeping the areas of use clearly separable.

Note: some interview subjects may not be aware of all current areas of use and therefore may suggest a present area of use as a future one.

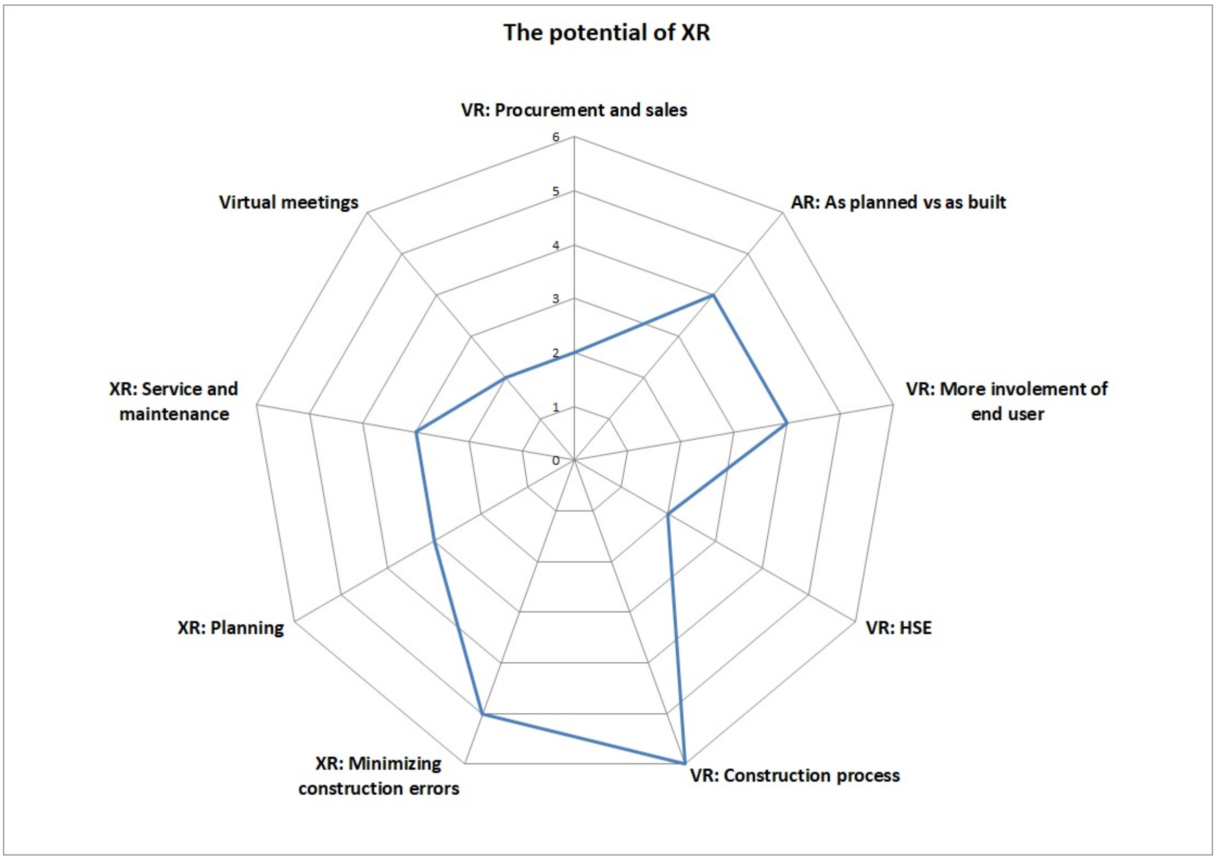


Figure 4.6: Graphic illustration of reported areas of potential regarding XR.

The most promising areas of use according to the interviews are:

1. "VR: Construction process": This area of use revolves around simulating the construction process in VR to identify the optimal order to build and look at the need for storage space for materials etc.

2. "XR: Minimizing construction errors": As previously mentioned, rework is a major problem in the construction industry. By looking at a design in XR, parameters such as dimensions and required work area can be established, and the feasibility of a solution can be tested in a virtual environment before actually building it. Some interview subjects also believed that collision control in VR could be beneficial.

3. "VR: More involvement of end-user": The involvement of the end-user as soon as possible is beneficial for any project, as earlier stated in section 1.1.

4. "AR: As planned vs. as built": The possibility that AR technology presents in terms of verification were recognized by several interview subjects. The possibility of superimposing a model view over the built structure offers a fast, easy and intuitive way of measuring build quality parameters such as alignment, dimensions and placement, amongst others. The interview with Niras and the literature review also proposed using an "as planned vs as built" approach for verification of progress. This will be discussed further in section 5.4.

5. "VR: HSE": This potential area of use revolves around using VR technology to identify and mitigate HSE (Health, Safety and Environment) risks. A construction site is a dangerous place [90]. VR could be used for construction safety training as a situated learning tool, as discussed in 3.4 and for safety inspection in virtual walk throughs [91].

6. "VR: Procurement and sales": This is not a construction industry application but VR has a great potential to convey information in an understandable manner to non-EAC professionals. It then follows that VR has the potential to be a great tool in a procurement phase of a project, possibly dealing with non-EAC professionals. It is common to sell real estate before the completion of said real estate (easily confirmed by looking up real estate for sale). By offering potential buyers to experience the product in a virtual environment, possible benefits may be gained.

7. "VR: Virtual meetings": The possibility of having meetings in VR where participants have the same view presents significant benefits. Being able to discuss an issue while being immersed in to a virtual world could provide a whole new level of understanding and problem solving. It also removes the previously mentioned risk of a split discussion when involving VR in a meeting.

8. "XR: Planning": Planning is a fairly broad term. In this context it means using XR technology to improve the planning process in a construction project. A logical way of using it could be using VR to run the build process virtually before starting it in reality, thereby identifying potential risks and problem areas. After the build process has started, it is more logical to move over to AR to be able to compare the built structure to the planned one. It makes it easier to identify areas that are behind schedule and perform quality controls. Having these parameters, the planning process would gain an increase in efficiency.

9. "XR: Service and maintenance": This has been discussed to some degree earlier.

Chapter 5

XR in Construction

The information presented is gathered from the literature review and interviews. The use of XR in engineering is a relatively new concept and therefore not as widespread as say 3D BIM models. A problem, especially when gathering information from literature about current applications of XR is that a lot of research in engineering and in construction informatics does not analyse existing phenomena. It rather proposes new solutions and improves technologies. There are mainly two problems with this type of research [59]. First, whatever improvement this technology offers can be disputed by the fact that the construction process has managed without this technology up until now. Why do we then need it now? Second, such research often consists of a prototype created by researchers. The prototype lacks the user friendliness and robustness to be a viable commercial product. Measuring the potential of XR based on such prototypes could lead to a conclusion on a false basis [59].

The author feels the need to point out that there is considerable difficulty to categorize applications as a current one or a future one. A technology and its applications do not have a precise time and date for implementation, so an objective assessment has been made by the author to determine the suitable categorization based on mentions and maturity.

Some statements in this chapter concerning future applications are speculations based on, but not directly supported by literature. They are derived by the author based on the experience gained in the subject throughout the process of writing this thesis. Some statements may therefore be perceived as lacking in references.

5.1 Current Applications of VR in Construction

This section will look at current uses of VR in the construction industry. To list an area of use as being a current area of use, a requirement of two separate mentions have been made. In this context, mention means something being discussed in a publication or in the interviews as a current (large scale) area of use.

5.1.1 Knowledge based work applications

The term knowledge based work is in this thesis used for work that typically requires an engineering, architectural or managerial background.

Construction site planning

Improper planning and site management are amongst the leading causes of delays in the construction industry [78]. An activity that involves both of these factors is construction site planning. By using VR, it is possible to create virtual versions of the construction site at all stages of construction (4D plus VR). This enables experienced project team members to identify potential problems in regards to material placement, crane placement, HSE risks, amongst others.

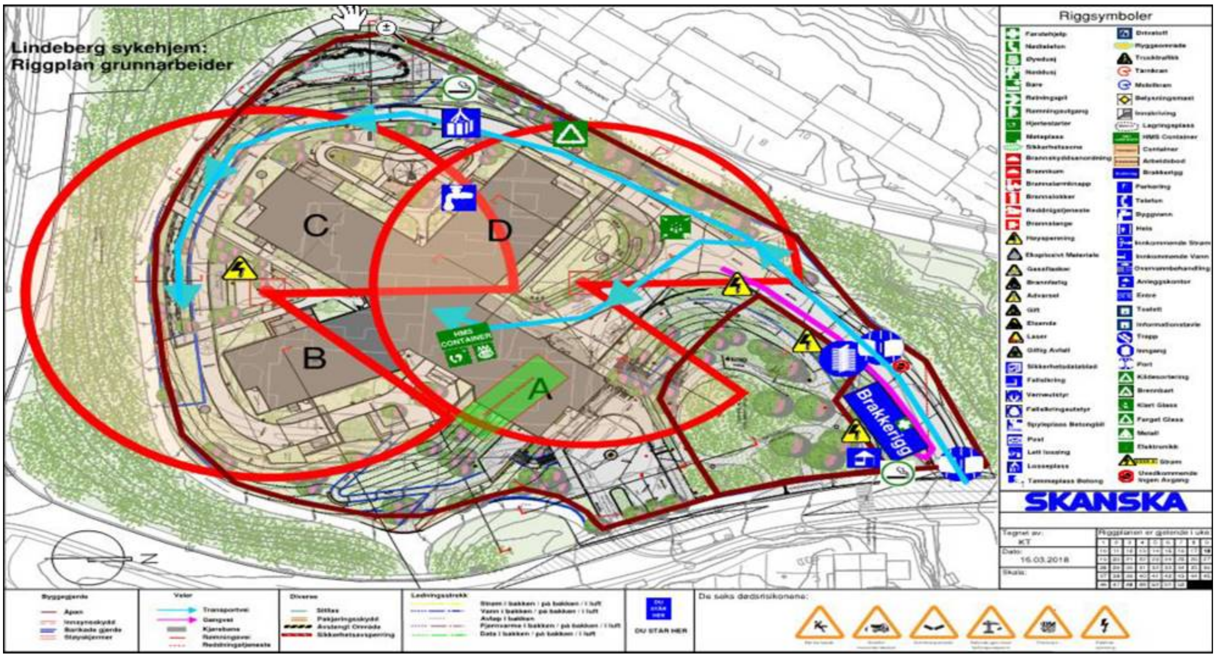


Figure 5.1: An example of a typical site plan. Picture provided by Skanska.

Testing

Testing is a fairly broad term. One could argue that all sections of this chapter in some way goes under the category testing. What is meant by testing in this context is to see if the finished design satisfies all criteria put down by the project owner and the users, before starting construction. From literature and interviews the following topics are certain to have been tested using VR:

Lighting design [92], [93]
Attempting to get a feel of the lighting conditions in a room from a 2D drawing or a 3D model on a computer is difficult. A better way is to experience it by walking through the area in question in a virtual environment. This reduces the chance of expensive supplementary work due to an inadequate result.

Exposure related problems
Something you do not quite get the feeling of when looking at a building using traditional methods is the exposure and view. In this context, exposure means how easy and how much you see from the outside, for example through a window. VR is perfect for this, allowing the user to look through a window from all angles, both in and out. This could for example show that a tree needs to be moved since it obscures the view or that a neighbour has direct line of sight in to an apartment's living room. Several interview subjects reported this as a current area of use.

Ergonomics and functional design [92]
Let us say that a hospital is to be built. The designers and engineers can come up with a buildable project. The problem is they are not the ones that will use it on a daily basis, they do not really understand the requirements of such a building. The ones that will use it, doctors, nurses and others, they might not have the same competence and experience with interpreting 2D plan drawings and 3D BIM models, but they know exactly what is needed in the actual hospital.

For this reason, there is a communication gap between the ones that know what they need and the ones that can provide it. VR bridges this gap by allowing the users to experience the building before starting construction. Skanska has for example used this in the development a hospital. Nurses were given the opportunity to see the patient rooms and walk around in VR. "Is this enough space?, Can I reach that from here?, What is the view of the patient?". Surgeons were able to experience the operating rooms as well and test them out in VR. This provides an excellent way of ensuring that all the needs of the users are met and avoiding change orders and rework after the start of construction.

Conceptual design

A construction project often contains special design solutions. The common practice is to make a mock-up of these special design features to determine the feasibility of the design and to determine if the design itself is as desired. This is obviously costly. VR today provides a close enough representation of the real world that it gives designers the confidence to make such design decisions using a virtual immersive model. It is also much easier to make changes to the design in a VR environment than on a real mock-up. An example from the US states that the savings from creating a virtual mock-up instead of a physical mock-up were as high as 90% [94].

Figure 5.2: An example of a typical mock-up [95].

This freedom of testing designs may also have a downside. A case study found that the VR model was more susceptible to client scrutiny [96]. This meant more changes of design, which again affected the schedule. It appears that the immersive virtual model makes clients more critical of the design. As previously mentioned, this was experienced by one of the interview subjects as well.

Another factor to consider is cost/time. Depending on the software of choice, it could require more time to create a VR model than a regular 3D BIM model. If the project is relatively simple, there is no need to create a VR model if all decisions can comfortably be made on the basis of a 3D model [96].

Visualization

Constructing a structure is a lengthy and expensive endeavour. Everyone with some experience from the construction industry knows that it is beneficial in terms of time and costs to consider all variables and have as much of the planning done before starting the build process [2]. A client may not have the same experience in interpreting 2D drawings or even 3D BIM models as an engineer or architect. A rendered image provides some detail but comes with its own challenges [97]. Traditional renderings often provide a misrepresentation of form, colour and lighting due to skewed perspective or unrealistic points of view, while the VR environment immerses the user so that they can experience it for themselves. Clients can even use the virtual environment for their own marketing purposes and training of staff.

VR bridges the gap between client understanding and the presentation of a design. Giving the client a HMD and allowing them to actually experience the structure is a way to ensure that all parties involved agrees on the project design and plan at the start of a project, avoiding change orders later [98]. A change order is a written order to the contractor signed by the owner and architect, issued after execution of the contract, authorizing a change in the work or an adjustment in the contract sum or the contract time [99].

5.1.2 Physical work applications

The term physical work is in this thesis used for work that typically is carried out by skilled workers. Examples of such work are the building of form-work, the casting of concrete and placement of rebars.

Training

There are mainly two areas where VR is used in training: Construction safety training, and equipment and operational task training.

<u>Construction Safety Training</u>
When considering construction engineering education and training (CEET), construction safety training is the second largest application of VR, only beaten by visualization and design education [100]. The reason for the large focus on construction safety training is due to the unfortunate fact that the construction industry is a high-risk industry [90]. As mentioned in section 3.4, VR is suitable for this type of training due to the immersive nature of VR compared to a traditional classroom environment.

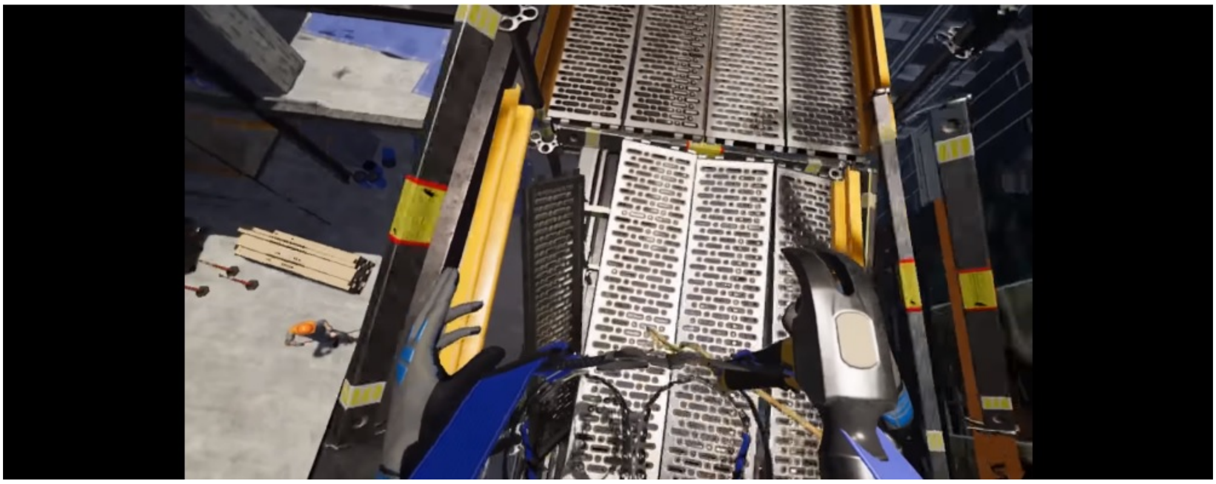


Figure 5.3: Screenshot from PIXO VR, a VR construction safety game [101].

<u>Equipment and Operational Task Training</u>
The traditional way of learning how to use equipment and carry out operational activities is a classroom environment followed by on-site training [100]. On-site training is a great way to learn but carries a high risk of damage to people still in training and risk of damage to equipment. By using VR, this on-site training can be achieved while mitigating the risk [102]. Another benefit is the cost-savings. You don't have to pay for equipment rental, fuel and materials.

5.2 Current Applications of AR and MR in Construction

Where VR replaces the real world, AR adds to it. This requires a different and, in some ways, more advanced technology [103]. Whatever device is used to experience AR needs to know where it is so that it can add information on top of what it sees. This could be image recognition or some form of GPS technology. To provide any real benefit, the precision of this spacial awareness needs to be high. Consider using AR to locate a cut-out. The precision required to avoid cutting existing installations is high. For this reason, the use of dedicated AR devices is not as widespread as VR devices. It is worth mentioning that smartphones can provide AR but with a limited usability in terms of the construction industry [59].

5.2.1 Knowledge based work applications

Quality assurance

The construction industry receives a lot of criticism about quality, cost, safety and speed. There are two main reasons for the criticism: Numerous individual parties with their own motivation, and the fact that construction projects are one-off's [104]. The performance of one party will influence the performance of the others. Having parties working for their own interests instead of in union splits up the construction process and it ends up as a series of customer and supplier relations. Unlike manufacturing processes, construction projects are usually unique. This leads to a somewhat non-standardized process, often resulting in changes of design.

Figure 5.4: Screenshot from a concept video demonstrating how AR could be used for quality assurance [105].

These factors make quality assurance difficult in construction projects [104]. Head mounted AR have been used in large scale projects and have a proven effect on quality assurance [106]. It enables team members to identify errors and deviations quickly and with ease, allowing them to take appropriate action. How head mounted AR helps in quality assurance is by having quick and easy access to drawings, comparing the discrepancy between the model with the built structure as an overlay, or by using the head mounted device to take measures and compare measurements with drawings. These features rely upon an AR device that have the necessary hardware, (such as Microsoft Hololens or DAQRI Smartglass) and a correct, up-to-date BIM model.

5.2.2 Physical work applications

Based on the interviews and literature review, it appears that AR technology seems to be at a point where no large contractor believes that the cost of implementation is smaller than the cost savings, in terms of physical work applications. This does not mean that it is not in use but compared to the amount of construction taking place, it is negligible. The literature review revealed that most available literature focus on prototypes and future applications, not current and well implemented applications. The technology is fairly new and holds great promise but at this time there appears to be no imminent benefit of implementing it. Examples of technologies that has great potential are the previously mentioned Trimble SiteVision, Microsoft Hololens and DAQRI Smart Glass. (Note: These are just examples of some promising technologies. Others may exist.)

5.3 Future Applications of VR in Construction

It is hard to say where VR- and XR technology will be in 5-10 years. Smartphones is an example of a technology that has had tremendous impact on our society and the industry over the last 10 years. Expecting such a huge impact of VR may be to exaggerate but as long as the public interest remains and the technology is further developed, it is reasonable to think that VR will have a key role in the future of the construction industry. As stated earlier, it is hard to predict the impact of a technology on the construction sector based on research proceeding from prototypes. After conducting a thorough literature review, the following area of use is recognized by the author as being the most promising.

5.3.1 Knowledge based work applications

The literature review and interviews provide little information about the future of VR in terms of the construction industry. The author believes that most applications have been discovered but further development of these applications will take place. This can include more functionality, streamlining the user interface, and new levels of collaboration in a virtual environment, amongst others.

5.3.2 Physical work applications

VR + Robot based construction automation

This future area of use is somewhat speculative but it supported by some literature. Controlling robots using a VR setup has been attempted in research projects and shows promise of being an application of the future [107]. Using robots on the construction site is a field similar to XR on the construction site in the way that it is in an early stage of development, but the potential benefits are recognized [108], [109]. Robots have the potential to reduce injuries while increasing precision of the work done and minimizing waste [110]. It has been shown that robots controlled by an operator immersed in VR has a positive effect on safety, when compared to an operator using a monitor [107]. Combining the efficiency of robots and the level of understanding of VR, the author speculates that several benefits could be gained in the construction industry. VR could be used to monitor the tasks carried out by autonomous robots or to operate the robots themselves, much like Remotely Operated Vehicles (ROV) in the offshore industry. Drawing further parallels to the offshore industry, it is reasonable to think robots would be used where the risk of injury to personnel is high, or where a task cannot be accessed by personnel.

5.4 Future Applications of AR and MR in Construction

There is a floating transition between “in development” and “implemented by industry”. A technology is not embraced by all and utilized 100% overnight. For this reason, the areas listed in chapter 5.2 could be listed here and vice versa. An attempt has been made to separate the areas of use based on maturity. Research and incremental improvements in the previously mentioned applications still takes place but as they have been discussed and potential advantages identified, they will not be mentioned again.

As for chapter 5.3, proposed areas of use are based on a literature review. Unlike chapter 5.3 however, it is also heavily based on the results from the interviews.

5.4.1 Knowledge based work applications

Construction site planning

Being able to see what exists beneath the ground, see what the building will look like in the future and see what materials are needed at what stage is a huge advantage when it comes to site planning. A construction site is consists of many layers. There are usually several installations at various depths, multiple cranes operating in the same space and other factors. By considering the current stage of a project and what the project team aims to achieve within a time frame, AR provides a unique opportunity for site planning by allowing project members to see all relevant information on top of each other in its actual geographical position. This makes construction site aspects such as material storage areas, lift zones and pedestrian zones more manageable to plan.

Verification of Progress

A recurring proposed application in literature and by interview subjects is using AR for the verification of progress. By synchronizing the BIM model to the schedule (4D), AR could potentially allow project team members to visualize a delay. This would be done by having the time appropriate model placed on top of the built structure using a portable AR device such as a smartphone or a Hololens (as built vs as planned principle). This could be developed even further, by linking a BIM model with both schedule and cost (5D). This would allow for a visual representation of a time-cost relationship. A proof of concept has been developed by one of the companies interviewed; Niras.

The benefits of 4D and 5D by itself is a whole new topic and will not be discussed further in this thesis.

Such an application shows great promise according to research [82]. Studies show that people prefer this visual form of progress control compared to for example traditional Gantt charts [59] A sufficiently smart software could even calculate costs of a delay based on such a comparison and propose actions to either mitigate the delay or gain advantages in other areas of construction.

Data Acquisition

There are mainly two ways it is believed that AR can help with data acquisition. First, it can be used by workers and inspectors on-site to document the current state of progress, resource quantity and resource location. Second, it can be used by the same people on-site to access blueprints and technical specifications of relevant components quickly, especially if the AR technology is advanced enough to understand what the user is looking at and then display the relevant drawings directly [82].

5.4.2 Physical work applications

Communication

The construction industry is very suitable for AR technology since it can enable users to obtain information directly on-site, instead of having to return to an office to access a PC [111]. By combining this possibility of direct information with communication, an even greater advantage could potentially be gained. The idea is that a skilled worker with a specific problem can look at relevant information with the support of an engineer or a manager through a sort of shared view. DAQRI advertises this as a feature with their products but documented use such as a case study have not been found. Some research about AR as a collaboration tool exists [112] but does not focus on the construction industry.

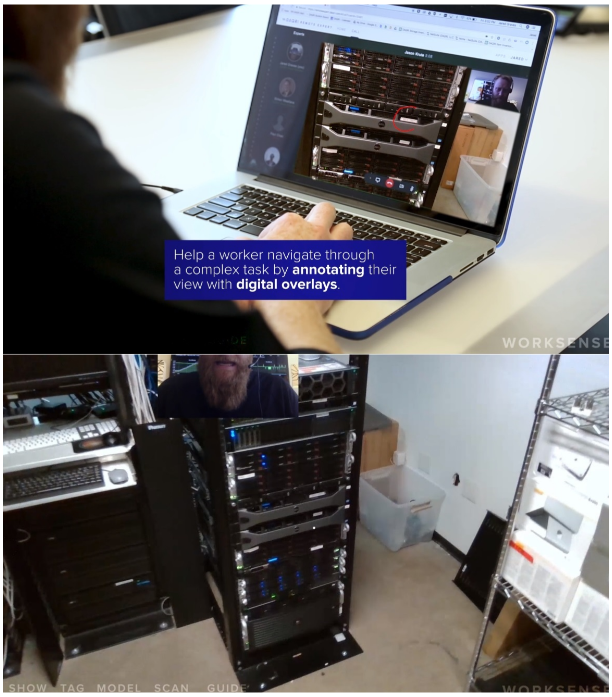


Figure 5.5: DAQRI shared view [113].

Figure 5.5 shows screen shots from a video demonstrating the use of DAQRI Smartglass with the shared view functionality in the DAQRI Worksense software. The top panel shows the view of someone assisting a worker on site, shown in the bottom panel.

Such an application could cut down on time spent in meetings and instead solve problems directly, as they emerge. The fact that the one assisting in the problem does not have to be present, allows for more flexibility in terms of the workplace. They are not required to meet face-to-face, something that is very beneficial especially when it comes to specialized competence, typically externally hired consultants and technicians. This flow of information goes both ways and could enable easier delivery of information about the construction site to managers. The flow of information is critical for the success of a construction project [82]. A study [114] found that communication and the retrieval of information are significantly enhanced when AR is used compared to more traditional means.

Chapter 6

Implementation of Technology in Other Industries

"Only a fool learns from his own mistakes. The wise man learns from the mistakes of others." - Otto von Bismarck [115]

This chapter will consider what can be learned from other industries. It will attempt to identify factors critical for success and typical problems that will have to be addressed.

The construction industry is generally slow to implement new technology and is known for being "low-tech" compared to other industries [116]. XR technologies presents a possibility to alter this perception. Considering the fact that the industry is low-tech, similar low-tech industries will be considered for a more direct comparison.

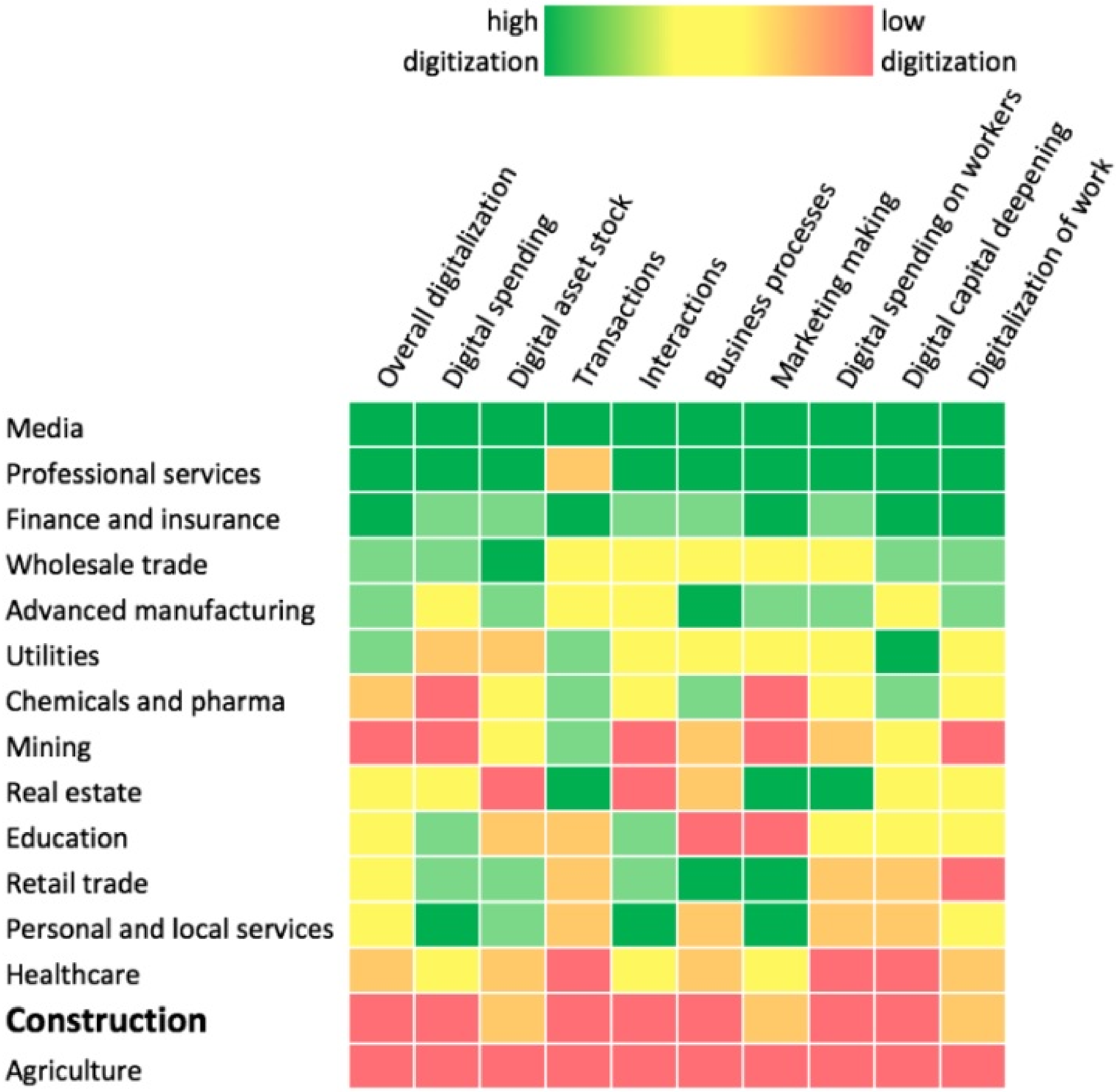


Figure 6.1: The figure shows the degree of digitization of different industries [116].

6.1 Case 1: Information technology in the UK hotel industry

A three-year research project by Whitaker [117] was conducted to investigate the impact of information technology on the UK hotel industry. Information technology (IT) is the use of computers to store, retrieve, transmit, and manipulate data or information [118]. Published in 1987, it investigates the organizational barriers to overcome for successful implementation of IT in the hotel industry. The introduction of digital systems as an improvement of the previous practice involving manual data handling presented a substantial shift in practice. This section will consider lessons learned from this situation and establish it in the context of XR in the construction industry today.

"It was assumed from the outset that the impact of information technology on performance, organisational structure, working methods, and employment is not determined by the nature of the technology itself. Rather, the outcome is a product of the decisions and behaviour of those who are in a position to direct and influence the design and implementation of technology."

Whitaker argues that it is not enough to simply provide a new technology or solution. It is up to those in a position to influence the design and implementation to make the proper decisions to facilitate a proper implementation. To put this statement in the context of the construction industry and this thesis, XR developers and VDC specialists must ensure that the technology is user-friendly, and that all requirements for carrying out a task are met. At a managerial level, a proper implementation process must be established. It is not enough to provide the technology without additional support.

Several other barriers have been identified by Whitaker. A key barrier that was identified and discussed in section 4.4.2 has also been identified by Whitaker; a willingness to change ones practice, especially at a managerial level. According to Whitaker, reluctance or inertia at a managerial level will slow down the implementation progress and can stimulate conservative reactions throughout the organization. Whitaker claims that this managerial caution is based on uncertainty about the future direction of technological development, possible obsolescence and the possibility of reduced prices in the future. Whitaker also argues that short term benefits are often used at a managerial level to measure performance. Doing so with XR, it is possible that it will be dismissed as a failed technology. From the interviews, very few interview subjects believed that their experience with XR (VR mostly) had resulted in an actual measurable time or cost saving but all interview subjects were positive to the technology and believed that it would result in savings in the future, after further use and implementation. It is therefore important to give new technology time to be accepted by the users. Going back to the case, if one were to compare a 1970's pre IT hotel industry to a 2010's IT hotel industry, which one is most effective?

6.2 Case 2: Field study of hospitals implementing new technology

A paper by Edmondson et al. examines how new routines are developed in organizations (hospitals) when an innovative technology is implemented [119]. The new technology in question is Minimally Invasive Cardiac Surgery (MICS). The hospitals exhibited striking differences in the extent to which they were able to implement the new technology, even though they all had top-tier cardiac surgery departments. This section will look at the findings of the paper and establish it in the context of the construction industry.

"Analysis of qualitative data suggests that implementation involved four process steps: enrolment, preparation, trials, and reflection. Successful implementers used enrolment to motivate the team, designed preparatory practice sessions and early trials to create psychological safety and encourage new behaviours, and promoted shared meaning and process improvement through reflective practices."

Edmondson et al. suggests that technology implementation is a process that follows four core steps. During the course of these steps, new beliefs, skills and collaborative routines are developed. Enrolment involves selecting and motivating participants for the implementation effort. Preparation describes activities such as practice sessions that stimulate the use of the technology. Trials involves using the technology. Reflection involves the discussion of the experience gained during trials. The results of the reflection are used in the next trial; it is an iterative process.

Though understandable, the suggested process model was found to be overly simplified in some cases. The model shows four discrete steps, whereas real-life activities can span over multiple steps. In the case of the hospitals, such activities were often coordination with other clinical groups. In a construction context, this is comparable to coordination between multiple disciplines in a project. It was found that the hospitals that were able to successfully implement the new procedure had a higher degree of boundary spanning. Boundary spanning refers to expanding the number of groups or members involved in a process [120]. This concept of increased success by increased involvement is well known in the construction industry. An example is ICE (Integrated Concurrent Engineering), a principle that aims to involve all relevant parties to the decision making process. [121]. The principle is often enforced as ICE meetings. In terms of XR, it could be logical to follow the same principle by having developers and users meet and follow the four implementation process steps together with a feedback system between the developers and users.

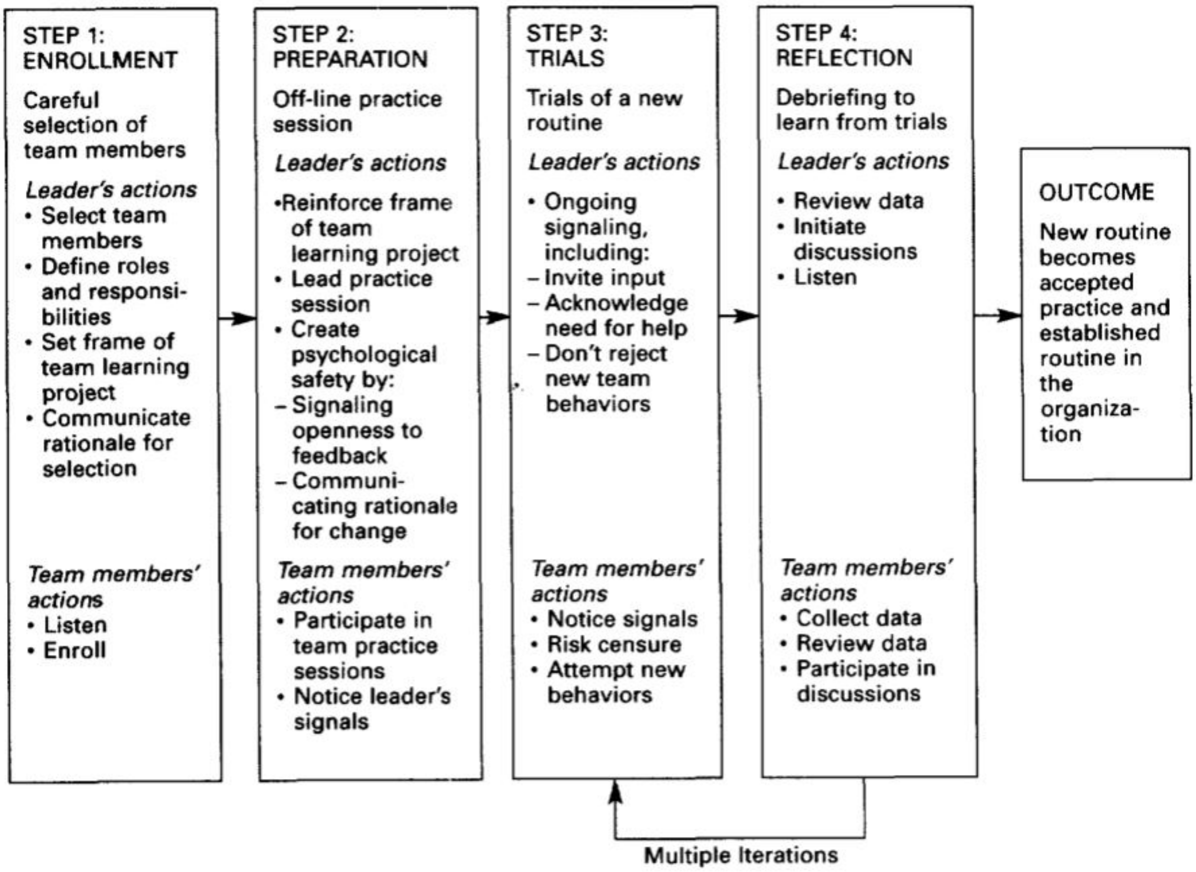


Figure 6.2: The figure shows the process model for establishing new technological routines [119].

Interestingly, Edmondson et al. found no link between senior management and the success of implementation. This is contrary to the findings of Whitaker in the previous case. This is likely due to the difference between the healthcare industry and the hotel industry. The author of this thesis speculates that the implementation of XR is more directly comparable to the implementation of IT systems in the hotel industry than the introduction of a new procedure in the healthcare industry. It is therefore recommended that senior management is involved in the implementation process and that their support is ensured. Edmondson et al. did however find a link between team leaders and the success of implementation.

"In trials, some team leaders motivated the others to endure the hardship that learning MICS entailed by focusing on benefits to patients. For example, Dr. J frequently communicated his growing confidence in the technology, and Janus team members shared a belief that patients benefited enormously from the procedure. Sophia enthused, "Every time we are going to do a MICS procedure I feel like I've been enlightened. I can see these patients doing so well..."

"Trials at Chelsea and Decorum and other low implementers were described in qualitatively different terms from those depicted above. At Chelsea, team members said that communication in the OR [Operating Room] did not change for MICS, and as a result, according to Martha, "There is a painful process of finding out what didn't work, and saying 'We won't do that again.' We are reactive. The nurses have to run for stuff unexpectedly." Team members reported being uncomfortable speaking up about problems".

A motivating team leader appears to be key in the case of the hospitals. It is reasonable to believe that some team members will require motivation to change their practice. This is valid in all industries. Considering the construction industry, the author suggests having project leaders prepared for the technological change, maybe in the form of a seminar or course. This is done to increase their own confidence on the topic and be able to lead by example, reassuring any project members sceptical to the new technology. If the project has their own BIM/VDC technician, it is possible to pass this responsibility over to them.

It may sound far fetched to compare the introduction of new technology in cardiac surgery (in 2001) to the introduction of XR in the construction industry today, but as this section shows, there is a lot to learn from other industries. Edmondson et al. makes the comparison between their study and the engineering industry themselves as well, recognizing similar problems to overcome when faced with the implementation of new technology. The healthcare industry is somewhat more hierarchical than the construction industry. Problems reported by Edmondson et al. based on a strict hierarchical order may be easier to overcome in the construction industry. The main findings of their study is the importance of a supportive team leader that encourages communication and motivates team members, and having the implementation process as an iterative process.

Chapter 7

Discussion

7.1 Expectations

Amara's law states that *"We tend to overestimate the effect of a technology in the short run and underestimate the effect in the long run"* [122]. Expecting an overnight revolution of the industry is pointless but by neglecting new technology all together you risk ending up in a position where you have to catch up to the rest of the industry.

This thesis generally presents XR technology of having the potential to have a positive impact on the construction industry. The literature review revealed that researchers are confident that the technology will have a significant impact on the industry in the years to come. Even if the principle of Amara's law is recognized and organizations give the technology time to mature, the possibility of false positives exist. Researching this thesis, the author encountered a positive, even revolutionary, view on the technology by other researchers. This (based on speculation) could be due to a confirmation bias in the research. Confirmation bias was discussed in section 1.6. A researcher may not wish to present findings that contradict existing theory, but rather elaborate upon it. This "need" to find a positive perspective may permeate some research in to the topic of XR technology. It is still the authors belief that XR will have a positive impact on the construction industry. To what degree remains to be seen.

7.2 Observations

The purpose of this thesis seemed unclear and somewhat unnecessary for the author at the beginning of the thesis. Mapping out areas of use was believed to have been done several times already and the benefits of XR seemed known. After conducting the interviews and reading available literature, a clear need for such a thesis became evident. Especially the interview with Niras provided insight in to their process and experience in working with VR and how little is actually known about how to utilize the technology in the best way. Applications would be suggested by project owners and end-users. Niras would follow up on these suggestions and create the relevant possibility of interaction. This demonstrates the current state of the technology; vast opportunities but unclear or unknown limits. This does not mean that Niras has limited competence with VR; they actually appear to be one of the more proficient companies out there in regards to VR.

The interviews are based on three interview groups. As an interviewer, the author experienced that people in the same group have a similar perspective and relation to XR, especially at Alrek Helseklynge. As a result of this, several of the interview subject's answers are similar. In a way this is positive: The statement of one interview subject is supported by the statements of the others. In another way this is negative: There is little variation in the answers due to similar experiences. In this thesis, all interviews have been face-to-face. This has involved some time spent travelling. An on-site visit provides considerable understanding and makes an interview easier. It is certainly better than a video call but the author argues that it is more important with more interviews (as video calls) than fewer on-site visits. A suggestion for future research is to conduct interviews with more people, using video calls or similar instead of on-site visits.

Chapter 8

Conclusion

This chapter will address the findings of this thesis in context with the problem description, as well as propose future areas of research based on the findings of this thesis.

8.1 Findings

The problems description states:*"In collaboration with Skanska Norway, this thesis will look at the potential of XR technologies to improve the cost- and time efficiency of the construction industry. This is done by considering current and future construction industry applications of extended reality technologies, and how these applications will influence the construction process"*.

An investigation has been carried out to establish how XR can benefit the construction industry, both now and in the future. Findings have been presented, discussed and qualitatively evaluated with the problem description as the premise.
The results from the interviews seem to agree with results from the literature study. XR is already improving the efficiency of the construction industry. The technology is currently not experiencing a wide-spread use, but as the technology is improved and wider implementation is achieved, it is reasonable to believe that XR technology will become a significant factor in the construction industry in the years to come. Assuming an increase in a XR technology precondition in contracts, it might even become essential.

The problem description specifies cost- and time efficiency. There exists very limited data to identify quantitative efficiency improvements due to XR technology. The thesis has rather focused on qualitative data and concludes that XR technology has the potential to significantly improve the cost-and time efficiency of the construction industry. This improvement is based on the benefits gained from using XR in all phases of a construction project. The most significant benefit found is based on the information enhancement experienced when using XR. Information is more accessible and more comprehensive. This enables users to make decisions earlier in a project and with greater confidence. It is believed that this will reduce the amount of changes to the design during construction and thereby reduce costs associated with design changes. The enhanced understanding is believed to result in clearer communication and more reliable decision making. This will in turn reduce time and resources spent on potential rework.

Areas of use, both current and potential future ones have been identified for both VR and AR. The common theme of these applications when compared to traditional means of visualization are clearer communication between team members and increased understanding of design. This in turn results in the reduction of construction errors due to flawed planning or a lack of understanding. By avoiding errors, potential rework is avoided, saving time and money. The findings of this thesis indicate that VR is more beneficial in an early phase of a project, where communication with non-AEC professionals takes place. An example is end-user decision making in terms of design decisions. AR seems to hold greater promise in the construction phase of a project. It has the potential to be a great tool for project members for planning, resource management and documentation. There are several benefits for skilled workers as well, such as direct information retrieval, and guidance through shared view. At the current time, the technology is not believed to have the maturity required for full-scale implementation. It is the authors belief that pilot projects and incremental up-scaling of use are important to build up and maintain competence to ensure a competitive advantage in regards to a technology that is believed to be significant in some years.

It is clear that it is not enough to simply provide XR; the implementation process must be properly managed as well. Several factors have been identified to increase the likelihood of a successful implementation. From the interviews, several factors where identified by the interview subjects. By the interview subjects at Alrek Helseklynge, unsuccessful implementation due to a lack of interest were identified as a potential threat. The solution to this was proposed as having a highly enthusiastic team member to motivate others to embrace the technology. This can also be seen in relation to case 2 in chapter 6. A key finding was the importance of team leaders. It appears that project leaders or someone else in the project team have to take on the responsibility of motivating others if there is a hesitation to use XR on a project. The author proposes a seminar or workshop for project members identified as being responsible for motivation. If possible, all team members should be offered this possibility of learning. A key feature of such an assembly should be thorough use of the technology to ensure competence and familiarity. By having a motivated team member with insight about the technology, another reported problem may be resolved: Some users may experience the use of XR as a sort of threshold to cross and a threat to their preferred way of work. By having someone (in a leadership position) demonstrating the benefits, it may sway sceptics to supporters.

The need for a plan was identified as a key factor by several interview subjects. It is natural to draw parallels to BIM in terms of this. the use of BIM in construction projects are usually regulated by a BIM plan. It ensures a clear strategy for the use of the technology. Similar work should be carried out to regulate the use of XR.

The most prominent problems when implementing XR is found to be scepticism in the industry, and that some people can perceive it as a ”threshold” to cross. Previously mentioned actions should be carried out to resolve these problems. It is also recommended that a quantitative study is carried out to measure the effect of XR to demonstrate the benefits. This can help convince sceptics and lower the threshold to use the technology. At the current time, not enough hard data exists to carry out such a study.

In conclusion, XR holds great potential to improve the efficiency of the construction industry. If the implementation process is properly managed, it is the authors belief that we will see XR change the entire construction process, from early design to project handover. However, if the implementation process is not properly managed, it is possible that the technology will dwindle to a simple gimmick. It is not the technology itself that will change the industry, it is the people utilizing the technology.

8.2 Further research

One aspect of VR that was not mentioned in any literature but repeatedly mentioned by the interview subjects was the commercial value of VR. By being an early implementer of new technology, a company displays a willingness to adapt and conveys a message to potential employees that the company strives for more. This reputation of being an early implementer and marked leader of XR solutions will fade over time unless continuous development, implementation and public exposure are maintained. By obtaining and maintaining a reputation as an innovative company, Skanska could use this as a recruitment tool to attract new employees and as a tool to gain the interest of project developers. The commercial value of XR technologies should be further investigated.

The field of XR technologies is currently experiencing a huge boost in research and development. The author experienced that new technology is introduced and announced in such a speed that several new technologies were introduced in the time of writing, from January to June. This demonstrates the need for keeping up to date and to continue to monitor and evaluate new possibilities. Examples of new hardware introduced (but not discussed in depth this thesis) are Microsoft Hololens 2 and Trimble XR10.

Several interview subjects reported that VR is a great tool to display and sell design concepts and housing. Using VR as an alternative for conventional house showings presents the opportunity of allowing clients to make desired choices early in the build process, even before the start of construction. It also enables companies to sell their product before finishing it. This application have not been discussed in this chapter 5 since it is not a construction industry application. It is suggested that further investigation in to this subject is carried out. The same goes for facility management. Several interview subjects and multiple articles [123], [124] states that facility management is a promising area of use for AR.

As mentioned in section 4.2.2, a quantitative study should be carried out to determine the value of XR technologies for the construction industry. At this time, there is not enough numerical data about the value of XR. Due to the nature of the construction industry, such a study might be difficult to conduct. No two projects are identical, so establishing a baseline project and a pilot project implementing XR for comparison is difficult. A suggestion is to establish Key Performance Indexes (KPI's) such as time performance, cost performance, quality performance, HSE incidents and client satisfaction [125]. Rating projects after completion enables the comparison between projects using XR and those who do not.

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Appendices

Interview questionnaire, English

Name, company, position

1. To what degree have you used XR?
2. Du you feel that XR is a gimmick or something that contributes to the construction process?
3. What have you used it for? If suggestions are needed:
    - (a) Procurement
    - (b) Design
        - i. Visualization
        - ii. Meetings
        - iii. Testing
            - A. Escape routes
            - B. Lighting conditions
            - C. Accessibility
        - iv. Other
    - (c) Construction
        - i. Site planning
        - ii. Identifying potential HSE risks
        - iii. Resolving technical challenges
        - iv. Meetings
        - v. Quality assurance
        - vi. Other
    - (d) Operation and maintenance
        - i. Locating technical facilities
        - ii. Other
4. What do you consider as potential problems when one is to implement XR?
5. In which areas do you believe XR has the most potential? What technology is best utilized by who?
6. What type of errors do you believe can be mitigated using XR?
7. Who in a project benefits most from using XR? (Project manager, skilled workers, project owner etc etc)
8. For Skanska employees: Have you heard anything about Skanskas plans regarding XR? Have you heard anything about Skanska and XR in general?
9. For Skanska employees: What do you believe is important to facilitate the use of XR in Skanska to a greater degree?

Interview questionnaire, Norwegian

Name, company, position

1. I hvilken grad har du brukt XR?
2. Føler du at XR er et gimmick eller noe som bidrar til byggeprosessen?
3. Hva har du brukt XR til?
   (a) Anskaffelse
   (b) Design
      i. Visulaisering
      ii. Møter
      iii. Testing
         A. Rømningsveier
         B. Lysforhold
         C. Tilgjengelighet
      iv. Annet
   (c) Byggefase
      i. Riggplanlegging
      ii. Identifisering av HMS risikoer
      iii. Løse tekniske problemer
      iv. Møter
      v. Kvalitetskontroll
      vi. Annet
   (d) Drift og vedlikehold
      i. Lokalisering av tekniske installasjoner
      ii. Annet
4. Hva anser du som potensielle problemer når man skal implementere XR?
5. I hvilke fagområder tror du XR har størst potensiale? Hvem for mest ut av hvilken teknologi?
6. Hvilke type feil tror du kan minimeres ved hjelp av XR?
7. Hvem i et prosjekt har størst utbytte av XR? (Prosjektleder, fagarbeidere, byggherre etc etc)
8. For ansatte i Skanska: Har du hørt noe om Skanskas planer angående XR? Har du hørt noe om Skanska og XR generelt?
9. For ansatte i Skanska: Hva tror du er viktig for å tilrettelegge for mer utstrakt bruk av XR i Skanska?

Preben Hammersland, prosjekteringsleder, Alrek Helseklynge, Skanska

1. I hvilken grad har du brukt XR?
   Jeg har brukt det i 6 uker på dette prosjektet. Har i tillegg fått en demonstrasjon tidligere der vi prøvde å selge inn VR til en byggherre. Det falt litt sammen og ble aldri brukt på det prosjektet.

2. Føler du at XR er et gimmick eller noe som bidrar til byggeprosessen?
   Det er et gimmick i positiv forstand. Det viser at Skanska og dette prosjektet bruker moderne teknologi. Det er en kommersiell verdi i dette.

3. Hva har du brukt XR til?

   (a) Romfølelse: Er det plass til alle installasjoner, er det mulig å jobbe her?

   (b) Visualisering

   (c) Innvolvering av sluttbruker: Gir sluttbrukere følelen av eierskap 2 år før bygget er ferdig, gjør at de føler seg involvert i prosessen, gir dem en følelse av at deres interesser er ivaretatt. Dette fører igjen til et bedre forhold mellom utbygger og sluttbruker.

   (d) Vurderer å bruke det til grunnsteinsnedsettelse: En statsråd kommer på besøk, BIM/VDC-avdelingen lager en interaktiv modell så setter statsråden ned grunnsteinen i VR. Når steinen legges ned reiser bygget seg. Dette er en bra måte å skaffe positiv presseomtale på og skape litt blest rundt prosjektet. Dette er igjen et slags positivt gimmick.

4. Hva anser du som potensielle problemer når man skal implementere XR?

   (a) Skepsis blant de som er etablert i bransjen og har sin praksis.

   (b) Nytteverdien er fremdeles uvisst. Dette ser ut til å være det store nye i bransjen men det må være en kjent nytteverdi før folk er interessert i å bruke det.

   (c) En tydelig plan på hva man vil ha ut av VR oppsettet på byggeplassen er nødvendig. Uten dette vil det nok bare bli liggende og ikke bli brukt.

5. I hvilke fagområder tror du XR har størst potensiale? Hvem for mest ut av hvilken teknologi?

   (a) AR: Jeg har hørt om konseptet men ikke brukt det. Jeg tror det har et stort potensiale i oppføring av bygg.Det gir deg mulighet til å gå fysisk rundt å kontrollere prosjektert løsning mot bygd løsning. Kvalitetssikring under oppføring er vel der det er mest å hente.

(b) VR: Jeg tro VR kan være veldig bra for sluttbrukere for å gi de en forståelse av hva som faktisk skal bygges. I tillegg er det lettere for sluttbrukere å ta beslutninger (byggherrebeslutninger) ved hjelp av VR. Tror også det kan brukes produksjonsplanlegging og HMS. Det tredje er prosjektering. Man kan se på plassbehov og rekkefølge på oppføring.

6. Hvilke type feil tror du kan minimeres ved hjelp av XR?
   Byggbarhet: Er løsningen byggbar? Plassbehov: Er det nok plass her til å drive vedlikehold etc?

7. Hvem i et prosjekt har størst utbytte av XR? (Prosjektleder, fagarbeidere, byggherre etc etc)
   Produksjonsledere kan sannsynigvis fange opp løsninger som ikke er byggbare ved hjelp av VR. Den samme feilen kunne kanskje ikke blitt fanget opp før den skulle bygges og da hadde det blitt produksjonsstopp. Sluttbrukere har nok også et stort utbytte av VR.

8. For ansatte i Skanska: Har du hørt noe om Skanskas planer angående XR? Har du hørt noe om Skanska og XR generelt?
   Jeg har ikke sett noen spesiell strategi men jeg har vært i samtaler med de som jobber med VR i Skanska. Jeg vet at de er flinke og ønsker å få dette implementert men jeg har ikke hørt noe fra Skanska sentralt. Det kan godt være min feil også, jeg er dårlig på å fange opp slik informasjon.

9. For ansatte i Skanska: Hva tror du er viktig for å tilrettelegge for mer utstrakt bruk av XR i Skanska?

   (a) Man må være veldig klar på den tenkte effekten og ha en klar formening om hva man skal bruke det til.
   (b) Faktisk ta det i bruk.
   (c) Sørge for at folk er forbredt på å bruke VR på møter, sørge for at alle får brukt det.

10. Kommentarer:
    Jeg mener at det er viktig at Skanska er frempå og blir en bransjeleder med denne teknologien som potensielt kan bli det nye store. Fremtidige bruksområder: Produksjonsplanlegging ved å kunne se risiko og gjennomførbarhet. Det å linke VR-modellen med tid (4D) har stort potensiale men det er tidkrevende å sette opp en 4D modell. Om gevinsten er større enn investeringen er uvisst men det virker som det har stort potensiale.

Magnar Rusten, prosjektleder for byggherre, Alrek Helseklynge, Stema Rådgivning

1. I hvilken grad har du brukt XR?
   Har brukt det i forbindelse med innsalg på et annet prosjekt der utleiearealer ble presentert (som en visning). Har ikke brukt det noe særlig på dette prosjektet selv.

2. Føler du at XR er et gimmick eller noe som bidrar til byggeprosessen?
   Jeg tror VR er nyttig, spesielt i møte med kunder og sluttbruker. De har ofte litt problemer med å lese og forstå tegninger som profesjonelle bruker.

3. Hva har du brukt XR til?

4. Hva anser du som potensielle problemer når man skal implementere XR?

   (a) Teknologisk kunnskap blandt de som skal bruke det kan være en hindring. Det kan oppleves som en slags terskel du må over og da vegrer man seg.
   (b) Det kan være sammenlignbart med implementeringen av BIM. Noe motstand blant den etablerte bransjen.

5. I hvilke fagområder tror du XR har størst potensiale? Hvem for mest ut av hvilken teknologi?

   (a) Det er et verktøy som kan være nyttig for å minimere byggefeil of effektivisere hele prossessen.
   (b) Alle type prosjekter fra eneboliger til større bygg kan ha nytte av det. Spesielt med leiligheter og boliger er at det vanligvis er en part som ikke har noe særlig erfaring med byggebransjen. Kan gjøre det lettere for de å forstå helheten og ta beslutninger.

6. Hvilke type feil tror du kan minimeres ved hjelp av XR?
   Alt ifra utsparinger til kollisjoner til tekniske løsninger i overganger etc.

7. Hvem i et prosjekt har størst utbytte av XR? (Prosjektleder, fagarbeidere, byggherre etc etc)
   Det er nok litt faseavhengig. I utviklingen av et prosjekt kan man raskt få avklaringer og beslutninger fra brukere. Bestemme størrelse, avgjøre volum etc. Det er også et viktig verktøy i produksjonsfasen for de som skal gjøre jobben. planlegge rekkefølger, oppklare spesialdetaljer etc.

8. For ansatte i Skanska: Har du hørt noe om Skanskas planer angående XR? Har du hørt noe om Skanska og XR generelt?

9. For ansatte i Skanska: Hva tror du er viktig for å tilrettelegge for mer utstrakt bruk av XR i Skanska?

Camilla Eide, Assisterende prosjekteringsleder, Alrek Helseklynge, Rambøll

1. I hvilken grad har du brukt XR?
   Jeg har brukt det en del på prosjektet, ca 10 timer.

2. Føler du at XR er et gimmick eller noe som bidrar til byggeprosessen?
   Det bidrar absolutt og jeg ser veldig godt nytten av det. Vi skal berike VR modellen i relevante soner for å se at alle sluttbrukere er fornøyde. Det er en del motstand i brukergruppen som per dags dato har en mer sentral beliggenhet. Ved å bruke VR håper vi å kunne få de med på laget og la de ta nødvendige avgjørelser.

   Det virker veldig nytting for folk som ikke har erfaring fra bransjen (sluttbrukere) å få en følelse av prosjektet i form av romfølelse og design.

3. Hva har du brukt XR til?
   (a) Vi skal etterhvert få inn en drone for å få riktig utsikt i den berikede modellen.
   (b) Interiørarkitekten har brukt det og brukergruppen skal inn i VR modellen for å bli kjent med kontorene og arbeidsplassene sine.

4. Hva anser du som potensielle problemer når man skal implementere XR?
   (a) Brukergrensesnittet er veldig viktig. Det må ikke være avskrekkende og alle må klare å bruke det. Det må også være enkelt å oppdatere modellen og generelt kreve lite datakunnskaper.
   (b) Noen merker at de blir dårlige av å bruke det.
   (c) Tilgjengelighet er viktig. Det må være en lav terksel for å bruke det.

5. I hvilke fagområder tror du XR har størst potensiale? Hvem for mest ut av hvilken teknologi?
   (a) Jeg ser nytten av å bruke det av prosjekterende i produksjon og installasjon for å avgjøre rekkefølge i byggeprosessen.
   (b) Sluttbrukere kan lettere fatte avgjørelser de føler seg trygge på. I tillegg kan de få en glidende overgang til for eks. en ny arbeidsplass istedet for å bare bli kastet inn i det.
   (c) Hjelper prosjekterende å faktisk forstå hvor store instalasjoner er før de faktisk skal bygge det og forstå plassbehov.

6. Hvilke type feil tror du kan minimeres ved hjelp av XR?
   Missforståelser mellom sluttbruker og utygger.

7. Hvem i et prosjekt har størst utbytte av XR? (Prosjektleder, fagarbeidere, byggherre etc etc)
   Der prosjektet vårt er nå ser det ut til å være prosjekterende.

8. For ansatte i Skanska: Har du hørt noe om Skanskas planer angående XR? Har du hørt noe om Skanska og XR generelt?

9. For ansatte i Skanska: Hva tror du er viktig for å tilrettelegge for mer utstrakt bruk av XR i Skanska?

10. Kommentarer:
    Jeg tror det blir det samme som med BIM, litt motstand i starten men at det løsner etterhvert. Siden VR oppsettet ikke er i bruk på en Skanska pc er det ikke mulig å ha automatisk synkronisering av modellen. Om en endring gjøres i BIM-modellen oppdateres ikke VR modellen automatisk. Dette er noe som hadde vært fint.

Jann Even Longva, Prosjektleder, Alrek Helseklynge, Skanska

1. I hvilken grad har du brukt XR?
   Dette er det første prosjektet jeg har vært på som har VR. Jeg har ikke brukt det så mye men det kommer seg nok etterhvert. Vi utfordrer hverandre litt på å bruke det.

2. Føler du at XR er et gimmick eller noe som bidrar til byggeprosessen?
   Vi kjøpte det jo inn for å prøve å få en nytte og verdi av det. Vi har flere type brukere her. VR gjør det enkelt for byggeherren å ta beslutninger angående overflater, fargevalg etc.

3. Hva har du brukt XR til?
   Visualisering av fasader og sånt

4. Hva anser du som potensielle problemer når man skal implementere XR?
   Det er en mulighet for at det ikke blir brukt. Vi kjøper det inn og får det opp og går men ingen bruker det. Plutselig er vi tilbake til sånn vi alltid har gjort det.

5. I hvilke fagområder tror du XR har størst potensiale? Hvem for mest ut av hvilken teknologi?

   (a) Hvis man i fremtiden kan gå inn i bygget med en form for briller (AR) og se hvor alt av rør og føringer kommer til å komme tar man mange av problemene man ofte diskuterer på møter og kan løse de med en gang. Kollisjoner, rekkefølge etc kan avgjøres med en gang ute på byggeplassen.

   (b) Spørsmål fra intervjuer: Tror du 4D pluss VR byr på fordeler i byggeprossessen? Det krever mye innsats og arbeid for å få en 4D modell til å fungere. Om man skal linke det opp mot VR krever det sikkert enda litt til. Om man hadde fått dette til å fungere knirkefritt er det mulig en slik modell kan være verdt all innsatsen. Man kan spole en uke frem i tid og se om andre prosesser og fag har mulighet til å begynne samtidig. Det gir nye muligheter å se for seg ting på og gjør planlegging enklere.

6. Hvilke type feil tror du kan minimeres ved hjelp av XR?

7. Hvem i et prosjekt har størst utbytte av XR? (Prosjektleder, fagarbeidere, byggherre etc etc)
   Jeg tror det går helt fra byggherre som skal ta beslutninger, rådgivere som skal prosjektere, produksjonsledere som skal produsere, lese og forstå tegninger. Det kan gi dem mye mer å se på en modell i VR istedet for for eks. tegninger. Fagarbeidere kan også ha nytte av det. Så alle kan potensielt ha nytte av det.

8. For ansatte i Skanska: Har du hørt noe om Skanskas planer angående XR? Har du hørt noe om Skanska og XR generelt?
   Vi har en kontaktperson i Bergen som satt oss i kontakt med rette folk i Oslo. Det

fungerer veldig greit. Det er veldig kort vei fra å ønske seg VR eller mer informasjon til å faktisk få det.

9. For ansatte i Skanska: Hva tror du er viktig for å tilrettelegge for mer utstrakt bruk av XR i Skanska?
   Et godt grunnlag i form av en god BIM modell. At byggeherren setter krav om digital byggeplass hjelper også på.

10. Kommentarer:
    Oppfølgingsspørsmål til spørsmål 2: Føler du det er en ren økonomisk besparelse som er større enn investeringen?
    Per dags dato føler jeg ikke det. Dette prosjektet er allerede godt besluttet. Veldig mye er allerede avklart. I tillegg er dette vårt første prosjekt med brukt av VR. Vi prøver selv å finne ut hva er nytten, hvordan kan det brukes og hvordan programmet brukes men vi har også god støtte fra BIM/VDC avdelingen i Skanska som gir oss den hjelpen vi trenger.

    Det er viktig at folk ikke blir redde for å ta i bruk ny teknologi og at de ikke stopper opp fordi ting høres for "svevende" ut. Man må tørre å hoppe ut i det og ikke gi seg etter et prosjekt. Vi får det kanskje ikke helt til her men på prosjekt nr 2 får vi det kanskje 90% til. På prosjekt nr 3 går det kanskje helt av seg selv og vi får det til 100%.

Karoline K. Sandvik, Prosjektingeniør, Alrek Helseklynge, Skanska

1. I hvilken grad har du brukt XR?
   Dette er første gang jeg bruker VR. Vi ble introdusert for det på Young Professionals Programme gjennom Skanska. Det fungerer fint for å understreke at Skanska ønsker å ha moderne, fremoverlente byggeplasser.

2. Føler du at XR er et gimmick eller noe som bidrar til byggeprosessen?
   Jeg tror det er veldig nyttig i HMS planlegging, fremdriftsplanlegging, kollisjonstesting, konstruksjonsrekkefølge og planlegge fremdrift. Det å kunne ta på seg VR brillene og for eks. se at det er en stikkontakt man må huske å trekke ledninger for er veldig nyttig. Jeg tror også det kan være nyttig å gi det til fagarbeidere som kan se andre problemer enn oss.

3. Hva har du brukt XR til?
   Jeg har bare vært her en uke så det har kun vært i bruk for visualisering. Det er en fin måte å sette seg raskt inn i prosjektet.

4. Hva anser du som potensielle problemer når man skal implementere XR?

5. I hvilke fagområder tror du XR har størst potensiale? Hvem for mest ut av hvilken teknologi?

   (a) Det er veldig nyttig når man prosjekterer å kunne gå igjennom modellen og se på byggbarheten. De kan også bruke det til å prosjektere inn HMS fra starten av. Man kan være på byggeplassen og identifisere (og minimere) farer allerede i design.
   (b) De ute på byggeplassen ser større sammenhenger og andre problemer enn funksjonærene.
   (c) For funksjonærene er det et nyttig verktøy for fremtidsplanlegging og sikkerhet.

6. Hvilke type feil tror du kan minimeres ved hjelp av XR?

7. Hvem i et prosjekt har størst utbytte av XR? (Prosjektleder, fagarbeidere, byggherre etc etc)

8. For ansatte i Skanska: Har du hørt noe om Skanskas planer angående XR? Har du hørt noe om Skanska og XR generelt?
   Vi ble introdusert igjennom Young Professionals Programme. Jeg syns det er veldig viktig, spesielt for oss som ikke jobber på hovedkontoret å få innsikt i hva de driver med og hvor gode BIM/VDC avdelingen faktisk er. De er jo veldig flinke.

9. For ansatte i Skanska: Hva tror du er viktig for å tilrettelegge for mer utstrakt bruk av XR i Skanska?
   Det er viktig å vise at det fins og la folk prøve det. Man kan for eks. gi folk oppgaver som skal løses i VR for å gjøre de mer komfortable med å bruke det. Det er viktig at folk faktisk opplever at det er nyttig og at det er et utbytte av å bruke det.

10. Kommentarer:

Sofie Bergqvist, Rådgiver, BIM/VDC, Skanska

1. I hvilken grad har du brukt XR?
   Veldig mye. Jeg jobber fulltid med det.
2. Føler du at XR er et gimmick eller noe som bidrar til byggeprosessen?
3. Hva har du brukt XR til?/Hva vet du XR har blitt brukt til?
   (a) Visualisering og testing, spesielt innenfor helsesektoren. Dette går på romfølelse av pasientrom og fellesarealer.
   (b) Vi har brukt det opp mot sluttbrukere på boligprosjekter. Det har i den sammenheng blitt brukt til beslutningstakning i forhold fargevalg, materialfalg etc.
   (c) Vi har diskutert muligheten for å bruke det opp imot HMS i forhold til rømningsveier etc.
4. Hva anser du som potensielle problemer når man skal implementere XR?
   (a) Hvis bruker får en dårlig opplevelse i VR kan det føre til motstand mot å bruke det igjen. Vi er veldig nøye på at opplevelsen skal være den beste når vi designer. Motion sickness, det å plutselig fly rundt og sånne ting må unngås. Det er veldig viktig at brukeren er komfortabel.
   (b) Vi jobber med å få inn hansker slik at man kan se egne hender i modellen. Det gjør at man føler mer at man er tilstede. Det handler igjen om å minimere alle muligheter for å gjøre brukeren ukomfortabel.
5. I hvilke fagområder tror du XR har størst potensiale? Hvem for mest ut av hvilken teknologi?
   (a) Det er vanskelig å svare på men jeg heller mot å bruke VR i tidlig prosjektering/tidlig i prosjektet uavhengig av prosjekt.
   (b) Når vi får AR muligheter tror jeg det kommer til å ha en veldig stor betydning for oppføring av bygg (byggefasen).
   (c) AR kan også brukes av sluttbruker til vedlikehold av bygget.
6. Hvilke type feil tror du kan minimeres ved hjelp av XR?
7. Hvem i et prosjekt har størst utbytte av XR? (Prosjektleder, fagarbeidere, byggherre etc etc)
   Jeg tror alle fra tømrere til prosjektleder har nytte av det. Fagarbeidere jobber med

sitt fag men VR kan gjøre det lettere å forstå helheten og hvordan deres fag spiller inn på andre fag.

8. For ansatte i Skanska: Har du hørt noe om Skanskas planer angående XR? Har du hørt noe om Skanska og XR generelt?
   Vi har ikke gitt ut en ofisiell plan men vi har utviklingsinitiativer på både AR og VR. Vi har en del målsetninger knyttet til dette. Vi kan nok bli bedre på å formidle informasjonen ut i firamet, Skanska er jo et stort firma.

9. For ansatte i Skanska: Hva tror du er viktig for å tilrettelegge for mer utstrakt bruk av XR i Skanska?
   Opplæring, god kommunikasjon med de som skal bruke utstyret, senke terskelen for å bruke det og avdramatisere teknologien.

10. Kommentarer:

Nava Shahin, BIM-rådgiver, Skanska

1. I hvilken grad har du brukt XR?
   Jeg har brukt det i freelancing prosjekter før jeg begynte her i Skanska. Nå prøver jeg å kombinere VR med parametrisk design.

2. Føler du at XR er et gimmick eller noe som bidrar til byggeprosessen?
   Jeg pleide å jobbe på NTNU. Der brukte vi VR og AR for å designe en lab. Jeg brukte VR og AR til å vise andre folk interiøret. Det var veldig nyttig. Jeg brukte AR på tablet. AR opplevdes litt begrenset med tanke på bruksområder akkurat i det prosjektet.

3. Hva har du brukt XR til?

4. Hva anser du som potensielle problemer når man skal implementere XR?
   Jeg har ikke så mye erfaring fra byggeplass så jeg vet egentlig ikke helt hvilke problemstillinger de har der. Uansett så ser jeg verdien av å kunne visualisere nå så nære virkeligheten som mulig og gjøre areal/volumtester.

5. I hvilke fagområder tror du XR har størst potensiale? Hvem for mest ut av hvilken teknologi?

   (a) Tilbudsfase: Selge inn prosjektet. Det er lett for AEC fagfolk å tolke 2D tegninger og 3D modeller. Det er ikke like lett for alle andre. En detaljert VR modell kan være det som skiller to tilbud og kan være den avgjørende faktoren.
   (b) Designfase: Visualisering
   (c) Drift/Vedlikehold: Man kan for eks lokalisere teknisk anlegg ved å bruke XR.

6. Hvilke type feil tror du kan minimeres ved hjelp av XR?

7. Hvem i et prosjekt har størst utbytte av XR? (Prosjektleder, fagarbeidere, byggherre etc etc)

8. For ansatte i Skanska: Har du hørt noe om Skanskas planer angående XR? Har du hørt noe om Skanska og XR generelt?
   Etter å ha snakket med Sofie Bergqvist er ikke dette spørsmålet relevant.

9. For ansatte i Skanska: Hva tror du er viktig for å tilrettelegge for mer utstrakt bruk av XR i Skanska?
   En god introduksjon med eksempler og steg-for-steg instruksjoner er viktig. I tillegg er det viktig at noen, for eks. prosjektlederen er komfortabel med VR sånn at de andre ser at det ikke er farlig å bruke og at det har fordeler. Om man lager en rapport på slutten dokumenterer man effekten slik at andre (på andre prosjekter) kan se at det faktisk fungerer.

10. Kommentarer:
    Det å ta beslutninger i et prosjekt ved å bruke XR tror jeg kan være et interessant felt å se nærmere på.

Arnulf Gausereide, Senior prosjektleder, Skanska

1. I hvilken grad har du brukt XR?
   Har brukt det litt selv og sett noen demonstrasjoner.

2. Føler du at XR er et gimmick eller noe som bidrar til byggeprosessen?
   Jeg ledet en prosjektutvikling. Det var ønske om at vi skulle bygge et fysisk hotellrom som en prøve. Istedet for å bygge et fysisk rom bygde vi et virtuelt et. Det sparer jo oss for masse penger og gjør det lettere å gjøre forandringer.

   Man har også to forskjellige "nivåer" av VR, cardboard-løsninger og mer vanlige VR-løsninger. De har sine fordeler og ulemper men hovedsaklig er det kost, bevegle-sesfrihet og grafikk det går på. I Noen tilfeller er en cardboard løsning tilstrekkelig for å få en følelse av et rom for eks.

3. Hva har du brukt XR til?

   (a) Lage et virtuelt rom i prosjektutvikling istedet for å bygge et fysisk rom.
   (b) Jeg har sett en byggherre håndtere innsynsproblematikk i VR.

4. Hva anser du som potensielle problemer når man skal implementere XR?
   Teknologien gir enormt med muligheter, gitt at man planlegger og strukturerer bruken.

5. I hvilke fagområder tror du XR har størst potensiale? Hvem for mest ut av hvilken teknologi?

   (a) I prosjekteringsfasen kan det være veldig nyttig, spesielt hvis det kombineres med for eks. ICE-møter. Det vil nok gi en innsikt og forståelse på et annet nivå.
   (b) Om man tenker på digital armering kan jo AR gjøre ting enda mer forståelig enn løsningen idag med tablet.
   (c) Jeg vil forvente mer AR etterhvert. Mulighetene der er enorme tror jeg.
   (d) Dette med digital tvilling til drift og vedlikehold virker lovende. Dette er en digital tvilling av det fysiske bygget som følger med ved overlevering som kan oppleves i VR (og potensielt AR). Da kan man jo sammenligne det som er bygd imot det som ble lovet samt bruke det til å lokalisere instalasjoner og slikt.

6. Hvilke type feil tror du kan minimeres ved hjelp av XR?
   Det som har med byggherrebeslutninger å gjøre kan nok minimeres med VR.

7. Hvem i et prosjekt har størst utbytte av XR? (Prosjektleder, fagarbeidere, byggherre etc etc)

8. For ansatte i Skanska: Har du hørt noe om Skanskas planer angående XR? Har du hørt noe om Skanska og XR generelt?
   Etter å ha snakket med Sofie Bergqvist er ikke dette spørsmålet relevant.

9. For ansatte i Skanska: Hva tror du er viktig for å tilrettelegge for mer utstrakt bruk av XR i Skanska?

10. Kommentarer:
    Vi må bare tørre å ta ting i bruk. Noe feiler vi på, noe ikke. Vi kan ikke sitte og vente på at alle andre skal gjøre det. Om man ser på utviklingen og teknologien som har kommet de siste årene ser vi nå at det er en klar fordel med å bruke det selv om det kan være vanskelig i starten. VR kan ha den samme prosessen. Det er så mange fordeler med VR, man har jo også det grønne aspektet ved det (midre fysisk bygging+mer effektiv prosess).

Antje Wigand, Prosjektutvikler, Skanska

1. I hvilken grad har du brukt XR?
   Ja, jeg har brukt det i et tilbudsprosjektprosjekt som gikk over et år. Vi brukte det i forbindelse med å sammenligne to forskjellige varianter av landskap.
2. Føler du at XR er et gimmick eller noe som bidrar til byggeprosessen?
   Det er nyttig fordi det gir alle som er med på prosjektet bedre forståelse. Selv om AEC fagfolk bør skjønne tegninger er det enda lettere med en VR modell.
3. Hva har du brukt XR til?
   (a) Visualisering
   (b) sammenligne/teste to design
4. Hva anser du som potensielle problemer når man skal implementere XR?
   (a) Det var litt skepsis i starten, spesielt fra de litt eldre. Det var usikkerhet knyttet til om dette faktisk bidrar og skaper noen verdi for prosjektet. Alle som turte å bruke det var veldig positive men det er det å ta det skrittet å ta det i bruk som kan være vanskelig for noen.
   (b) Noen blir kvalme av å bruke VR briller.
   (c) I et møte er det bare en person som vanligvis bruker brillene mens resten ser det samme på skjerm. Det blir ikke helt det samme som å se igjennom VR brillene. Dette fører til at det blir en delt diskusjon med to forskjellige perspektiver. At alle på møtet hadde hatt briller og kunne sett på samme modell hadde vært en fordel.
5. I hvilke fagområder tror du XR har størst potensiale? Hvem for mest ut av hvilken teknologi?
   (a) Det har absolutt potensiale i en sammspillsfase eller når man jobber opp mot bruker.
   (b) Det er veldig nyttig når man jobber med noen som ikke er (EAC) professjonelle, for eks. ved boligsalg.
   (c) Ved å kunne få kollisjonskontroll inn i en virtuell verden hadde det nok vært nyttig.
6. Hvilke type feil tror du kan minimeres ved hjelp av XR?
7. Hvem i et prosjekt har størst utbytte av XR? (Prosjektleder, fagarbeidere, byggherre etc etc)

8. For ansatte i Skanska: Har du hørt noe om Skanskas planer angående XR? Har du hørt noe om Skanska og XR generelt?

9. For ansatte i Skanska: Hva tror du er viktig for å tilrettelegge for mer utstrakt bruk av XR i Skanska?
   De som har brukt det en gang kommer nok til å bruke det igjen. Det er bare å få folk til å bruke det den første gangen.

   VR koster jo ekstra også. For at folk skal være villige til å bruke det må nytten kunne dokumenteres. Dette gjelder spesielt om man har prosjekter litt utenfor de store byene der VR kanskje ikke har blitt brukt enda.

10. Kommentarer:

Christian Bolstad, VDC Spesialist, Niras Stavanger og Johnny Sætre, Disiplinleder VDC, Niras Stavanger

1. I hvilken grad har du brukt XR?
   J.S: Jeg brukte det for første gang i 2016 i forbindelse med en rettssak.

2. Føler du at XR er et gimmick eller noe som bidrar til byggeprosessen?
   Rettssaken dreide seg hovesdaklig om en endring i designet av en demning som gjorde armeringsarbeidet mye mer omfattende og kostnader knyttet til dette ekstra arbeidet. Vi ble leid inn for å objektivt illustrere kompleksiteten av armeringen. Tegninger og BIM-modeller gir egentlig ikke et skikkelig inntrykk av det, spesielt ikke for dommere og advokater. VR fungerte i denne sammenheng veldig godt for å illustrere for "vanlige folk" noe byggeteknisk.

3. Hva har du brukt XR til?

   (a) Visualisere/illustrere design: Illustrere kompleksitet for dommere i en rettssak.

   (b) Testing for sluttbruker: Arbeidere på en fabrikk fikk teste arbeidsområder på en fabrikk før de begynte å bygge. Dette gikk på plassbehov og lysforhold

   (c) Visualisering av grunnarbeider: På den samme fabrikken ble grunnarbeider visualisert i VR. Dette demonstrerte for involverte hvor vanskelig tilkomst på byggeplassen ville bli under grunnarbeidene.

   (d) Noen på fabrikken ville teste om de fikk en tralle gjennom en åpning. Vi lagde en tralle med en visuell effekt og en lydeffekt som varslet når trallen krasjet i noe.

4. Hva anser du som potensielle problemer når man skal implementere XR?

   (a) Det er såpass nytt at det kommer software- og hardware oppdateringer hele tiden. Vi lager noe som fungerer kvelden før presentasjon men som ikke fungerer på selve presentasjonen. Når du har folk som er skeptiske til VR i utgangspunktet hjelper ikke slikt veldig. Om man er skeptisk i utgangspunktet vil man henge seg opp i de 2% som ikke fungerer istedet for de 98% som faktisk gjør det. Stabiliteten i hele systemet/teknologien er en utfordring.

   (b) Folk henger seg opp i visuelle ting som ikke har noe med saken å gjøre. "Det vinduet skal ikke være der, den veggen er ikke grønn". Man må tilpasse modellen til hvem som skal se på. Om du skal vise det til en ingeniør går det fint men om det er for eks. en sluttbruker kan det være en ide å bare vise akkurat det du er interessert i at de skal se på, for eks. ved å gjøre resten av modellen grå og steril.

   (c) Eldre personer har en tendens til å slite med å bruke teknologien. Det har såklart noe å gjøre med teknologiforståelse og hvor lett man tar til seg nye ting men det er jo synd fordi du må forenkle modeller og kanskje fjerne funksjonalitet.

5. I hvilke fagområder tror du XR har størst potensiale? Hvem for mest ut av hvilken teknologi?

    (a) Det å kunne knytte valgmuligheter i en VR modell opp mot kost og tid (VR+5D) tror jeg har stort potensiale. Vi har utviklet et "proof of concept" i Unity som lar deg bytte på tre forskjellige løsninger for belysning. Ved å variere mellom de ser man tilknyttet tid for arbeider og kost, i tillegg til at vi har lagt inn solforhold.
    (b) Virtuelle møter der alle ser på samme modell og samme problem med all relevant info virker veldig lovende.
    (c) Jeg ser for meg mer prosjektering direkte i det virtuelle miljøet.
    (d) Det blir kanskje etterhvert slutt på tegninger. Alt er digitalt. Se for deg alle gå rundt på en byggeplass med AR briller og kunne hente de tegningene og modellene de trenger der og da. Det er såklart veldig vanskelig å forutsi og blir bare spekulering.
    (e) Det å bruke AR for oppfølging på byggeplass virker lovende. Det å kunne gå rundt på en byggeplass og sammenligne det som er bygd med et overlay som viser det planlagte er nok noe som kan bli vanlig.
    (f) Høyrisikooppgaver der du har en sjanse på å gjøre det riktig kan simuleres i et så realistisk virtuelt miljø som mulig og dermed forbrede arbeiderne på hva de skal gjøre og luke ut potensielle problemer før den faktiske jobben gjøres.

6. Hvilke type feil tror du kan minimeres ved hjelp av XR?

7. Hvem i et prosjekt har størst utbytte av XR? (Prosjektleder, fagarbeidere, byggherre etc etc)

8. For ansatte i Skanska: Har du hørt noe om Skanskas planer angående XR? Har du hørt noe om Skanska og XR generelt?

9. For ansatte i Skanska: Hva tror du er viktig for å tilrettelegge for mer utstrakt bruk av XR i Skanska?

10. Kommentarer:
    Hver gang vi viser VR til noen sier de "tenk så kult det hadde vært å kunne gjøre det og det". Det er ofte slik vi finner ut av hvilken interaktivitet vi bør ha i VR modeller og finner ut hvordan vi bør utvikle modellene.

    Spørsmål fra intervjuer: "Vet du om møter i VR er i bruk i stor skala noe sted?" J.S: Det er ingenting som er i bruk i stor skala fordi det kommer så mye ny teknologi på en gang. Da jeg begynte i bransjen holdt det å dra på konferanse annehvert år og du var relativt oppdatert på hva som skjedde i bransjen. Nå må du nesten være på nett døgnet rundt for å få med deg hva som skjer. Første gang jeg så BIM tenkte jeg at jeg hadde ca. 1 år på meg å bli god i dette før bransjen stikker fra meg. Det er 11-12 år siden. Der vi er idag trodde jeg vi skulle være etter 2-3 år på det tidspunktet. Folk har en stor tendens til å overvurdere teknologi på kort sikt og totalt undervurdere det på lang sikt.