Universitetet i Bergen

Institute of Information and -Media Science

Master thesis

Enhancing the Performance Of Instrumental Tasks In Construction Through Immersive Augmented Reality Technology

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Research Question:

RQ main:
How can immersive technologies enhance precision in the domain of construction?

RQ1 Academic:
What is the correct level of immersion for practical work such as construction based on analysis of immersive technologies and theories?

RQ2 Practical component:
What do construction personnel think works well and what could be better in immersion technologies to better precision in construction?

Chapter 1: Introduction

This master thesis is a cooperation between Teklab at the University of Bergen and one of the leading Scandinavian contractors, Veidekke, and the tech company Trimble. Trimble is one of the biggest tech companies in the world in the domain of construction.

The goal of this thesis is to use interaction design principles on immersive augmented reality (AR) technologies in construction to figure out what the right degree of immersion is for AR tools to be useful in construction. By providing better precision than is already possible. Specifically, the insights that have been made in this academic study aim to give general insight into how one can successfully implement MR technology in construction for it to be useful, safe and satisfying to use for the worker. These insights will then be applied to an AR device known as Trimble SiteVision (TSV) in the attached evaluation, which serves as the practical component of this thesis. TSV is a tool that is actively used by Veidekke. The practical component is a business oriented evaluation that is created with the intent of being useful to Veidekke.

This thesis will utilize interaction design and human computer interaction (HCI) principles actively to further the research. In this modern world where every sector utilizes advanced technology, media and interaction design is heavily involved in all domains that utilize digitized gadgets. Construction is one of these domains. This is the first cooperative project between the field of Media and Interaction Design at UiB and the construction business.

Often when we hear about immersive extended reality (XR) technologies, it is about virtual reality and entertainment. This thesis will however approach XR technology in an instrumental way, instead of communicative usability. What value can it contribute to solving practical tasks in everyday work life? Specifically in construction.

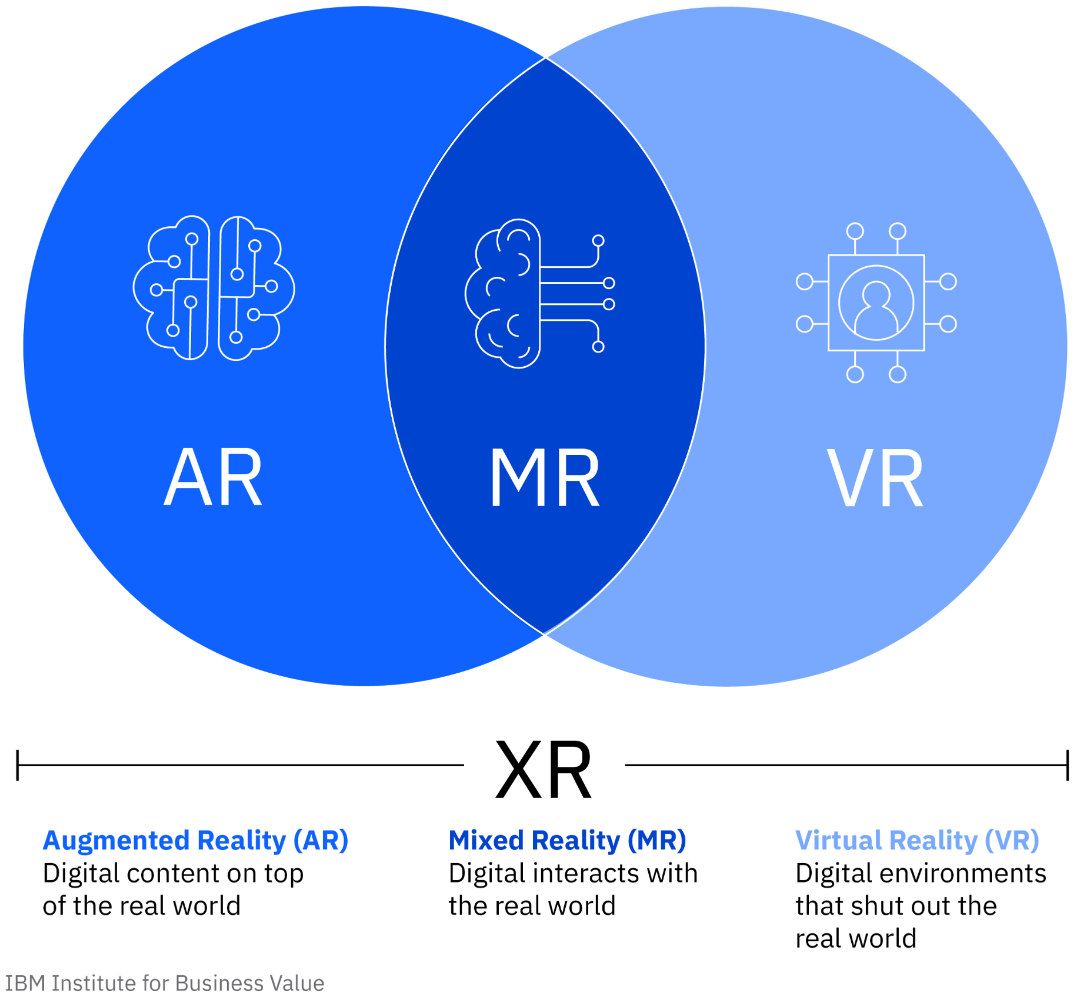

Figure 1: Different types of extended reality. IBM

In order to avoid confusion, we will map the terms being used so that the reader can follow along. As figure 1 explains. Extended reality (XR) is the common term AR, MR and VR. AR displays holographic content on top of reality, VR fully immerses you in the digital world, and MR allows for interaction with digital objects in the real world.

AR equipment is being utilized in many sectors today. Such as health, entertainment, education, military and construction. In order for the technology to work properly and produce satisfactory results, one has to consider user experience (UX) when designing the user interface specifically for completion of tasks within its respective domain.

Structure

As mentioned, this thesis consists of two different parts, relating to RQ1 and RQ2.

Part 1: The Academic Component

The academic text consists of an overall analysis of how immersive technology can increase precision and workflow in construction. Here we will study immersive tools and technology used in construction up to this point. We will explore immersion and immersion as a property of solving challenges. A critical analysis of the potential downsides of implementing this new technology will follow. At the end of the academic thesis, the methods for data gathering will be presented. These methods are used in the second part.

Part 2: The Practical Component

This insight in immersion technology for construction will be further explored for evaluating the device known as Trimble SiteVision. This is a professional evaluation aimed to be useful for Veidekke and the construction business. It is an user experience oriented evaluation with concrete examples that propose problems from the industry. Then solutions are presented based on co-design and human computer interaction principles. It is written in Norwegian in a rhetorical way to reach construction business professionals. It is an easy read and is of sleek design. Each iteration of this evaluation has been proof-read and critiqued by my contacts in Trimble & Veidekke, as well as my supervisor at the University, Lars Nyre.

Introduction to Instrumental Immersion in Augmented Reality

Using AR to solve useful tasks is being done in multiple domains. Pilots of the F35 fighter jet are equipped with an advanced AR helmet that provides previously unobtainable abilities. With 6 cameras attached all around the jet, the pilot is able to see “through” the jet with an angle of 360 degrees to be able to see as much of the landscape underneath and around as possible. The pilot can zoom if he/she wishes. Even when the pilot is not looking, the system is scanning for dangers that it displays to the pilot in the corner of the helmet (Moynihan, 2016). This is only some of the functions it has. In healthcare surgeons can use it to display the intestines of a person through their skin before cutting them up. In education teachers can use it to visually display examples of complex mathematical concepts. In behavioural psychology it can be used to examine facial expressions with artificial intelligence to help therapists understand the emotions of the patient.

The possibilities of using immersive technologies in an instrumental way to create value exists in almost every domain. These might not seem directly cost effective as the costs of this equipment are high, but the return of investment is clear as it improves the quality of the work being done, and it is cost effective by eliminating ambiguity and error through better communication.

This is what AR is on a basic level. A very advanced form of visual communication. Some concepts are too complex to be verbally explained and some numbers and structures too big for us to comprehend as an abstract concept. Visual communication presents another angle of view to a concept. Using images to convey a message together with natural language leads to people understanding each other better.

As mentioned in the introduction, when one reads or talks about immersion; storytelling and video games are often the topic of the theme. Virtual reality (VR) and augmented reality (AR) are very popular mediums for entertainment. AR games such as Pokemon Go have taken the world by storm and VR allows users to immerse into other worlds spatially. This thesis seeks to look at the instrumental value of immersive technologies, rather than looking at it as entertainment. We will see how it can be utilized to be useful in solving everyday challenges related to practical work. We will need to look at what exactly immersion is and what separates these types of immersion to see what type of immersion we are dealing with. When we know this, we will be able to discuss and evaluate the degree of immersion that is necessary for assisting workers in solving practical tasks.

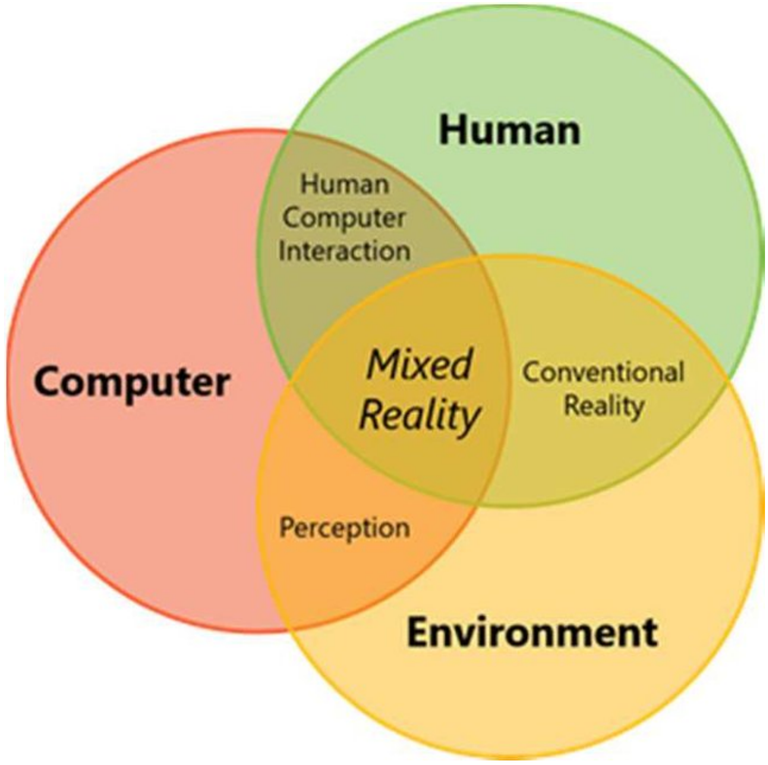

Figure 2: Graph describing the interaction between humans computers and environment. (Human-Computer-Environment Relationship, 2018)

Figure 2 will be central throughout this thesis. It is very relevant when looking at technologies developed for construction. Here one can imagine that the environment is the construction site. The human aspect is the ability of the worker, and the computer aspect is the tool/technology that the worker has at his/her disposal.

In order to utilize augmented reality well in solving tasks at the site, the balance of these factors should be suitable for the purpose at hand to some degree. We will explore this further throughout the project.

Motivation

My motivation for doing this is curiosity about augmented reality technologies potential in the future. One day everyone might walk around with casual AR glasses. I want to learn more about how it is used today and use my competence to help take the technology to new levels.

When I decided to write about AR in construction I called up a friend who is a construction engineer and asked him to recommend contacts in forward thinking companies in construction. One of them referred me to Øyvind Svaland in Veidekke, so I called him and told him that I was interested in working together. This led to the cooperation that made this thesis possible. Øyvind introduced me to Anders Hoie from Trimble, since he was his connection in Trimbles offices in Norway. Trimbles products are the AR/XR devices that are mostly used by Veidekke. Therefore it was natural that one of these devices were to be evaluated.

Veidekke

In this project I worked closely with the Construction company Veidekke. Veidekke is one of Scandinavia's leading contractors. With 8200 employees, Veidekke has the ability and competence to take on any type of construction assignments and road maintenance.

Veidekke builds apartments, houses and private commercial buildings such as offices, malls, schools, health centers and more. They have 7-800 ongoing projects at all times in Scandinavia and have contributed to landmarks such as the Opera in Oslo, The Munch Museum, Holmenkollbakken and Hardanger bridge. (Veidekke, 2021)

In this project, they have aided through project lead in extended reality at Veidekke, Øyvind Svaland. He has helped in developing a suitable and useful problem space that can be researched within their ranks.

Trimble

Trimble is a global technology and service provider within agriculture, building construction, civil engineering and construction among other things. Their solutions are used in over 150 countries worldwide, and they are located in over 40 countries. Among many technologies, they have provided Veidekke with frameworks such as the web application Trimble Connect, which is a cloud-based tool that gives the users the possibility to collaborate online in a secure manner.
Trimble is also the company behind the device that is in focus in this project. The Trimble SiteVision. Trimbles close relationship with Veidekke has made technical sales engineer in Trimble Norway, Anders Høie a prominent partner of this project.

Innovation in the Norwegian Construction Business

The Norwegian construction business is a huge sector with a lot of people and a huge amount of projects all the time. According to my contacts in the business, implementing change in the systems that are already in place is hard, and replacing the systems is even harder. It is hard because it requires teaching the vast amount of people that work in construction new technologies. Many of these workers have been practicing construction techniques the same way all their career and do not wish to learn new tricks the last couple of years before retirement. Implementing change can be expensive, but when the technology in the long term saves the industry money, it is a sensible investment. However, Trimble has said that the Norwegian construction business is ahead on innovation and testing new technologies for construction, compared to other countries. Therefore they are eager to cooperate with Norwegian construction companies in receiving feedback on their devices and are more than happy to cooperate on projects like this.

Trimbles Mixed Reality Equipment

Trimble has created two different Mixed Reality technologies specifically designed to be used in construction. One of them is a cooperative effort with Microsoft. This is the Trimble XR10 which is a modded version of Microsoft HoloLens 2 (Left in figure 3), integrated with a hardhat. Microsoft HoloLens 2 are glasses that provide tangible holograms projected in front of your Eyes. The other device is the Trimble SiteVision (TSV). TSV is of lower fidelity than the HoloLens 2, as it is a handheld mobile mounted device. This does not however suggest that XR10 is better. Since it is a tangible Mixed Reality in its early stages, XR10 is an early version of this type of technology and has a higher learning curve. In this project I will be focusing on Trimble SiteVision as it is more likely to be widely used within the industry in coming years.

Figure 3: Trimble XR10 (Left), Trimble SiteVision (Right)

User Experience and User Centered Design

This project requires and provides an understanding of user centered design (UCD). Which is to design with the end user in mind. This is done to maximise the user experience (UX) of using the technology. UX is the sensations a user feels when interacting with the technology.
This is all part of the field of human-computer interaction (HCI). Which focuses on the interaction between humans and computers.

Donald Norman says in his book “The Design of Everyday Things” that as new technology, applications and methods of interaction emerge and evolve, study and experimentation in that field is required to establish principles of good design related to the technology. (Norman,2013, p.8)

Norman argues that the solution should be human-centered design (HCD). HCD is an approach to design that puts human needs, behaviours and capabilities first. As these qualities are considered, a designer can meet these criteria. According to Norman, this is because good design starts by understanding human psychology as well as technology. To successfully design good user experiences one has to consider how the technology communicates with the human. This is to signal to the human what actions are possible, what is currently happening, and what is about to happen. (Norman,2013, p.8)

Augmented Reality devices such as Trimble SiteVision are part of the beginning of AR devices that are being used to solve useful tasks and assist people in their working life. As Norman said, study is required when new technology appears. In the case of using the same technology (AR) in different industries, it has to be tested and evaluated to ensure optimal user experience and usability within that industry. This thesis seeks to aid this process in the construction industry.

As this thesis focuses on a practical implementation of the technology, usability is important. Previous colleague of Norman and usability designer Jakob Nielsen is known for co-founding the Nielsen Norman Group together with Don Norman. It is an American

Consultant firm which specialises in user interfaces and user experience. Nielsen has invented several usability methods, including the popular heuristic evaluation for usability. (Nielsen, 1994)

User Experience (UX)

Good user experience is the main goal in the field of interaction design. Rogers et al (p. 30) presents this definition to interaction design. “Designing interactive products to support the way people communicate and interact in their everyday and working lives. Put it another way, it is about creating user experiences that enhance and augment the way people work, communicate and interact.”

Good user experience is however subjective. One user can have a great experience using a certain service, while another user hates it. Therefore creating a good user experience for all might be impossible. What we interaction designers do is rather to design for the user to have a good experience. (Preece et al. 2015)

To do this, one has to get to know the users while wielding the technology one wants to improve. In the case of Augmented Reality equipment. It has to be fast, easy to understand and effortless to use in order for it to replace the current technologies. To get to know the user, User Centered Design principles were used. User experience is the value that is delivered to the user when interacting with the product. In order to understand how to create a satisfactory user experience, I chose to go with the User-centered Design philosophy. (Hierholzer, 2013)

User Centered Design

User Centered Design (UCD) is a development philosophy or approach. It is often used as an iterative development process. It is an approach to design that keeps the users in focus throughout the phases of development. Norman writes that users are often frustrated with everyday things. As technology gets more complicated, it has to remain easy for the user to understand how to interact with the technology. This means that the device has to communicate effectively with the user. It is when problems arise that good design is important. Norman states that designers need to focus their attention on what goes wrong. Doing this, one can identify and have the device communicate to the user what went wrong, which could decrease the amount of stress put on the user as they don't have to figure it out themselves. (Norman,2013, p.9)

UCD user-focus is on planning, designing and developing a product. What processes one chooses to use depends on what type of project to use. This is often a mix of research and UX design techniques. Normans philosophy of user-centered design changed our way of looking at human and computer interaction, UCD processes seek to involve users actively at every stage of the design process to ensure that the results are satisfactory to the user.(Nordbø, 2017, p. 31-33)
An UCD process' stages often include the steps modelled in Figure 4:

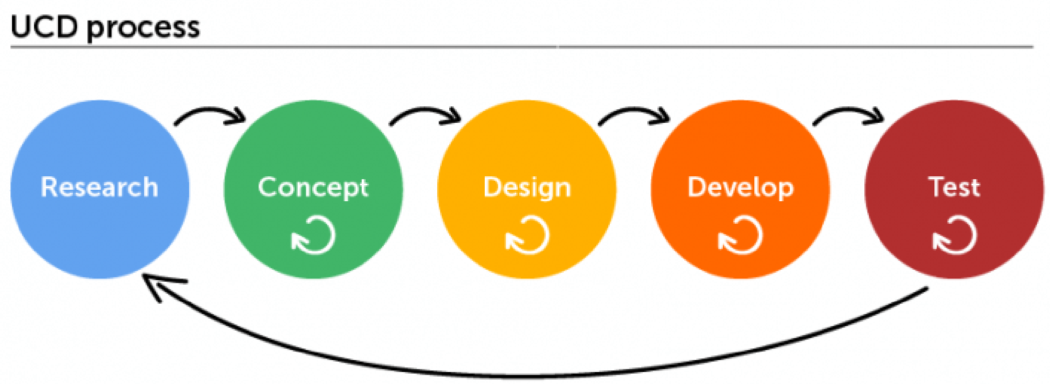

Figure 4: (UXPlanet, 2018)

Involving users from the beginning of the project has always been considered in this project. It has benefited from this because I am emerging myself in a discipline that I have no hands-on experience within. Therefore the research includes recurring meetings with contacts that have experience in this discipline.

Chapter 2: Entrenched Technology

Introduction

The field of construction has existed for thousands of years. Since the early days humans have used various materials gathered from the earth to raise structures to protect us and comfort us from the outside world. Whether it be to keep us warm and comfortable during harsh weather or to seal us off from outside threats such as wild animals and other malicious people. As society grew, the necessity for more, bigger and increasingly complicated structures arose. When cities grew, space became limited, but there was still a need for more. For all this time, engineers have been creating tools to help build with greater precision. The goal of this development is to remove ambiguity, which results in greater accuracy.

This chapter will first explore building technology that has aided in building with better accuracy throughout history to create an understanding of how the technology evolved into the complicated tools that we are looking at in this thesis. The chapter will also present the most common digital tools that are being actively used in construction today and relate it to Veidekke and the Norwegian construction business. After finishing this chapter, the reader will have an understanding of the technologies that have been the precursors to the implementation of augmented reality equipment in construction.

Tools of construction in humanities early days

Historian Yuval Noah Harrari claims that the human ability to pick up objects with our hands through concentrations of nerves and finely tuned muscles in our palms and fingers was and is a huge anatomical advantage. This advantage turned humans into the most advanced and dangerous species on the planet. The more one could do with one's hands, the more successful the creature is. Our hands have allowed us to create tools. The ability to use and create tools as an extension of ourselves allows us to perform tasks with precision that otherwise would have been impossible. To have an abstract idea and manifest it into the real world is an ability that seemingly only humans have. Humans capability for abstract thought and the anatomy of the human body is a good combination to result into a crafty creature. This combined with our ability to socially communicate intersubjective ideas and concepts, made way for synergy that allowed for raising structures. (Harari, 2009, p10)

Today, this process is being taken to the next level. We are at the point where we don't have to waste resources to manifest a concept of an idea in the real world. Rather we can create data rendered or holographic representations of the concept we wish to bring to life. In the world of construction, this is obviously very beneficial.
The process has come as far as having almost perfect holographic assistance right in front of your eyes, showing you exactly where to place an object. Improving accuracy and removing ambiguity in the process of raising a structure.
But how did we evolve from crafting hammers from rock and wood to augmented reality?

This chapter will focus on the evolution of accuracy in construction and engineering history. Accuracy in construction regards preparing, cutting, shaping and placing different types of materials with great precision to be able to build more advanced and complicated structures allowed by building engineering physics.

Back to the basics. The Stone Age

In the stone age people had access to a variety of materials such as rock, bone, antlers, wood, grass and hide. These materials could be used to create axes, adzes, scrapers and more.(Whirlwind, 2014) With axes and scrapers, a builder can shape wood in many different ways.(Wu et al, 2019) Shaping wood the way one wants it to makes way for creativity in construction. This type of construction did not rely on any civil engineering expertise, but rather on manual labor techniques. (Bright Hub Engineering, 2009)

Copper and Bronze Age, and the dawn of civil engineering

The bronze age brought forth sharper tools that allowed us to carve wood into different shapes. These shapes can be put together in different ways, depending on the way it is carved. With these tools one could shape materials with greater precision, and thus a more complicated structure with a wooden frame came forth. With the help of early versions of rope made of reed plant fibers it was now possible to raise larger wooden structures, recognizable in today's housing units. It is assumed that the science of civil engineering emerged roughly around the same time as the wheel, as transportation became important.

The pyramids constructed in Egypt during 2800-2400 BC could be considered the first large structures ever created along with the Great Wall of China, constructed around 200 BC. These structures are themselves fantastic feats of ancient civil engineering and precision. (Bright Hub Engineering, 2009)

It is believed that the Egyptians made use of ropes, rollers and sledges and invented levers, ramps, lathes, ovens, glass, paper and many other still relevant materials. (Whirlwind Team, 2014) Construction of an almost perfectly geometric pyramid is not easily done by simply drawing the blueprints and building from its instructions. The Egyptians were the first civilization to document techniques for developing tools to create rope. Rope was used to drag and lift objects but also as an important architectural tool. The arithmetic rope, also known as a knotted rope or the thirteen knot-rope, is an arithmetic tool used to solve mathematical and geometrical problems. It was often used by architects to construct circles, equilateral and right-angled triangles as seen in Figure 5 . (Arithmetic rope, 2019)

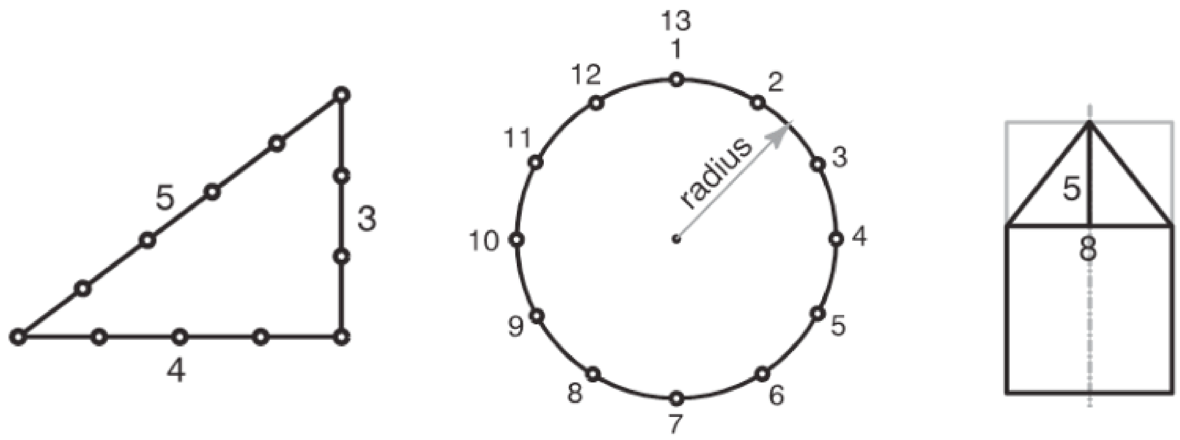

Figure 5 Arithmetic rope shapes (Nielsen F, 2010)

The Iron Age and precision tools

Around the same time, the utilization of new metals such as iron, allowed humans to create superior tools, like the frame saw and the hand plane which made cutting and shaping wood an easier task, allowing humans to fell and work bigger trees with more efficiency. Timber could now be efficiently cut and shaped into planks and posts.

Figure 6: Modern Iron Plane, Iron Plane (Plane Tool, 2021) (Left) Iron frame saws, (Framesaws, 2017) (Right)

Ancient Cities

Clay and stone was also used extensively in Greece, where they made advances in plumbing and general heating. Urban planning became important. The Greeks were supposedly active users of the waterwheel and the crane.(Whirlwind, 2014)

The Romans created large complicated structures in their cities. Understanding the physical laws that govern structural engineering has roots in the third century BC, from the greek mathematician, physicist, engineer, inventor and astronomer, Archimedes. In his work "On the Equilibrium of Planes", he presents the Law of the Lever, which states that:

"Equal Weights at equal distances are in equilibrium, and equal weights at unequal distances are not in equilibrium but incline towards the weight which is at the greatest distance."

He used these principles to calculate the areas and centers of gravity for various geometrical figures. Archimedes's work on calculus, geometry and equilibrium of planes together with Euclidean geometry support much of the understanding of structures in modern structural engineering, allowing future engineers to build with better precision. (History of Structural Engineering, 2020)

Age of Science

In the 17th century, Galileo Galilei, Robert Hooke and Isaac Newton laid the foundations of modern structural engineering with the publication of their separate scientific works. In Galileo's publication; *Dialogues Relating to Two New Sciences (1638*). He presented the first scientific approach to structural engineering by outlining the strength of materials and motion of things, and a first take on trying to develop a theory for beams. (History of Structural Engineering, 2020)

Robert Hooke followed up on this in 1676 with the first iteration of Hooke's Law, which provided a scientific understanding of the elasticity of different materials and how the materials behave under pressure.
Isaac Newton added an understanding of the fundamental laws governing structures with his *Laws of Motion* in 1678.(History of Structural Engineering, 2020)

Improvements in the construction industry skyrocketed from here. Now one could calculate measurements rather than estimate them from experiments and experience. Iron and glass was now used more often in construction.

This was also the age of the modern and accurate theodolite which allowed for building and planning with greater accuracy. "A theodolite is a precision optical instrument for measuring angles between designated visible points in the horizontal and vertical planes." They were traditionally used for surveying land, but were also very popular in construction and urban planning. (Theodolite, 2021)

With this instrument, angles can be accurately measured and used to draw plans. The more modern version of the Theodolite is called a total station as seen in figure 7 to the right. The total station is able to measure angles and distances electronically and sent directly to computer memory instead of having an active observer writing down the readings. The modern total station is actively used by Veidekke to survey land. (Theodolite. 2021)

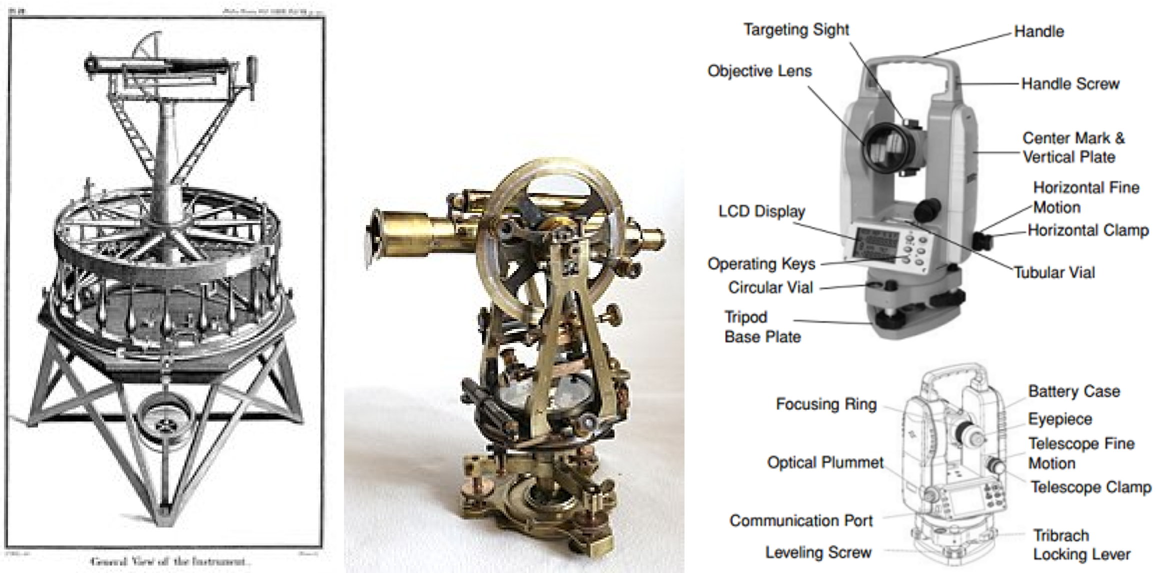

Figure 7: Jesse Ramsden's Theodolite, 1787, Theodolite Wiki (Left), 1910s Theodolite,(middle), Modern Theodolite, Survey Equipment (right) (Theodolite, 2021)

The Industrial Revolution

With the industrial revolution in the 19th century, builders had access to faster and better transportation in the form of steam engines. This made it easier to move materials. We also saw the dawn of machine tools such as machine cut nails. Explosives were actively used and optical surveying equipment such as the Theodolite became a standard tool for making measurements. (Whirlwind, 2014)

The Last Hundred Years

In the 20th century, construction changed a lot. People started building skyscrapers after the invention of the elevator. With the help of motorized cranes, power tools and prefabricated parts, the construction process sped up.
This was also the century for safety equipment, such as the hard hat and hearing protection. (Whirlwind, 2014) In the modern day of construction a new process of construction emerged. This process is what we call traditional design. Traditional design was used by Veidekke, who started out in the 20th century. Since then Veidekke has evolved with the business.

Traditional Design

Figure 8: Traditional Design: 2D Design - Engineers on the left, draftsmen on the right using traditional methods to develop blueprints for construction (Brouwer)

Traditional design is a form of 2D design. In traditional design it is common that each of the involved parts of the team works on separate industry drawings with the sole focus on the elements of the projects that they are responsible for. That means that architects draw on one paper, and engineers on another. They design their part on tracing papers. Tracing papers are sheets of paper with high opacity that allows the different specialists of a team to draw on top of each other's work.(Czmoch & Pekala, 2014). The downside of this technique is that when you have drawn the lines, you cannot make any changes.

The basis of projecting building was for centuries and still is two dimensional drawings of the designed building, developed with the agreed upon principles of all participants of the team. The problem is that the architectural sketches often differ a lot from the final and structural design. This is because architects often use 3D elements, sketches of bodies, and engineers use 2D plans or drawings. (Czmoch & Pekala, 2014).

Computer Assisted Design (CAD)

CAD is like traditional design, 2D design. It is a software that seeks to modernize and help the design process by digitizing it, thus supporting the calculations of the construction through computing power. Even though it is not the newest technology in the field, it is still very efficient and is being used in many Norwegian construction firms.

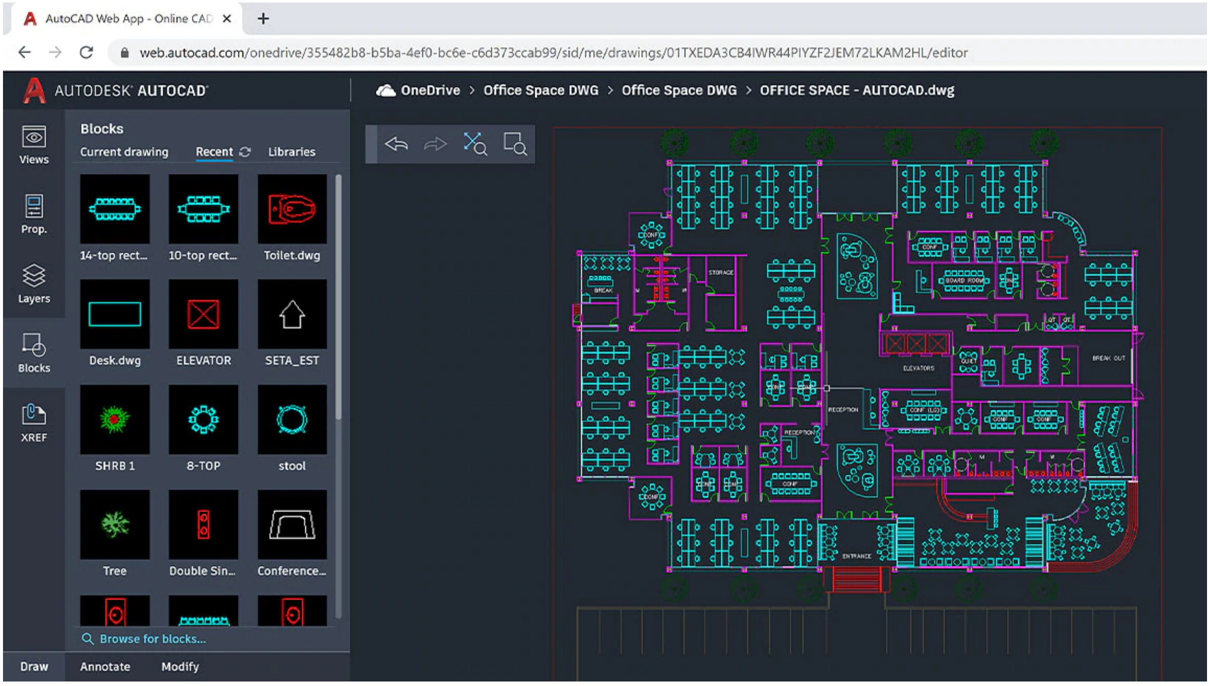

Figure 9: CAD, 2D model designed in AutoCAD (Autodesk, 2021)

CAD made it far easier to navigate blueprints to get a more precise understanding of what is being built. It was easier to collision check the elements and to make changes. Traditional design with the help of CAD was for a long time the way of designing blueprints for building and other constructions. The design process is a job for a large team of people consisting of architects, engineers and project managers.

CAD software has been around for a while, and developers have had time to work on them. Learning new technologies can be time consuming, especially if you are very efficient in working with CAD software and learning something new might slow down your work efficiency, for a while. The goal of new software and technology in the field is to be able to convey information better with newer technology. CAD is still used in Veidekke and other construction companies today.

Now in the last decade a new modern software seeks to normalize 3D design models in the world of construction with Building Information Modelling (BIM).

Building Information Modelling (BIM)

The acronym BIM is either translated as Building Information Modelling or Building Information Management. The British Standard Institution Specification for information management for the capital/delivery phase of construction projects using building information modelling defines BIM as “The process of design, construction and use of the building or facility infrastructure using information about virtual objects”. (PAS 1192-2:2013) Simply put, it consists of 3D animated elements that can be interacted with through a desktop application. BIM is used to design building models and to calculate the correct attributes of elements, such as material density, positioning, relations and collision detection to mention some.

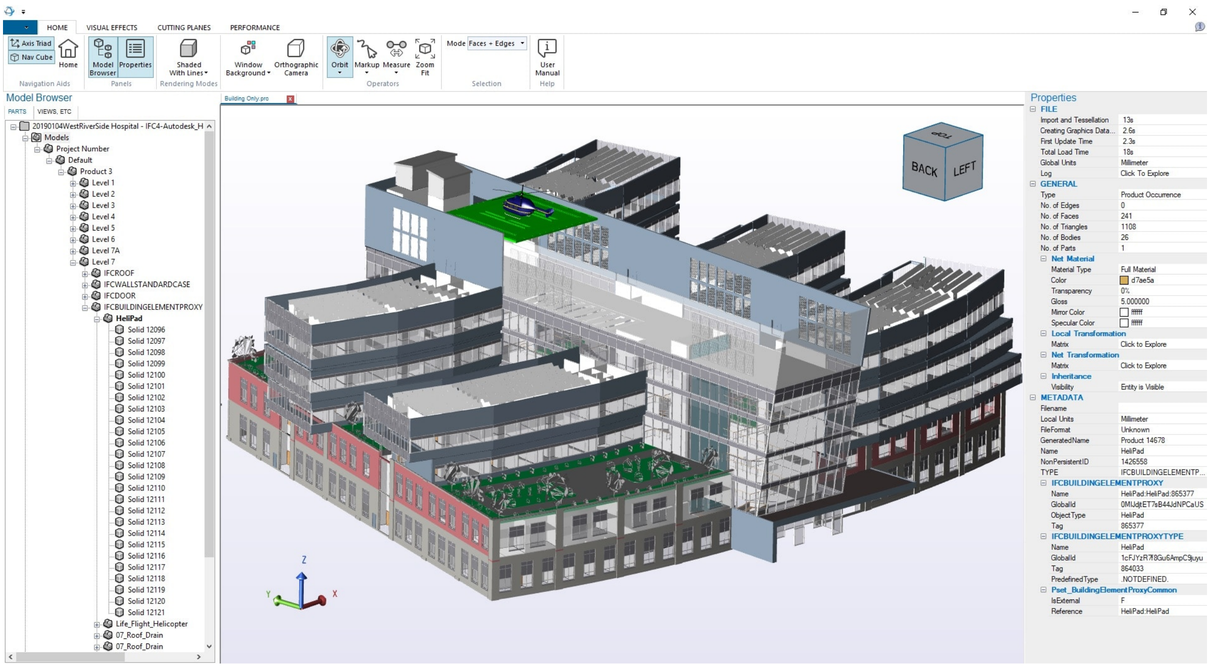

Figure 10: BIM, 3D model designed in *Autodesk Revit*. (Frausto-Robledo, 2019)

In 2014 Czmoch and Pakala described BIM as “[...] the next step in the development of computer-aided design. In practice, instead of several specialized documentations containing architecture design, landscape design, construction and installation designs as well as bills of quantities and cost estimates, we have one 3D model with a database containing all above information.” They present obvious benefits of using BIM instead of regular CAD software. Both BIM and CAD require more time to set up, but the benefit of the result is greater because it results in less ambiguity than a 2D drawing, is easier to make underway changes, and has greater collision detection. This results in very precise models. Even though the benefits of BIM seem to outweigh those of using CAD, there are still a lot of people and companies utilizing CAD software instead of BIM.

Still use for the old methods

As CAD tools have been implemented by designers for centuries, the traditional design method of drawing blueprints is still one of the best practices when it comes to small and medium sized projects, mainly because of its cheap costs. This however requires a well educated designer with the experience of being a member of a design team on a construction site.

Collision Detection

Collision detection's purpose is to alert the user when two objects in the design are colliding. It has always been an important aspect of interdisciplinary coordination in the design process of construction. To decrease collision is to increase precision. By the help of layering designs on tracing papers, one can help to spot collisions visually. CAD 2D uses a similar approach by having each layer in different colors in the computer software. BIM takes this to the next level by implementing collision detection algorithms and computer graphics developed by the video game industry. The goal of BIM collision detection algorithms is to be precise and exact rather than fast.
Collision detection is a hugely beneficial functionality of BIM and can be seen as three different categories. Technological collisions, that is watching over the sequence of assembly and the delivery schedule. Also keeps track of the number of workers and how long it will take to complete the construction. light collisions, which are free spaces that are required in order for the assembly of an installation. And heavy collisions. When two objects occupy the same space
(Czmoch & Pekala, 2014)

Collision detection allows workers to build with greater precision. One could say it’s the other way around too; Tools that allow you to build with greater precision prevents collision. Advanced collision detection in real time with mixed reality could be a system that alerts you to new collision events as construction goes on. BIM collision detection alerts you when you model the structure, but if you are out on site and the construction differs from the model because you or somebody else has made a mistake, artificial intelligence could be used to calculate what is off and alert you to potential upcoming collisions.

Accuracy

Common usage of blueprints and traditional drawings are being traded for data generated 3D models that allow the user to interact with the “blueprint” with great detail. Still, this 3D figure they have interacted with on a flat screen surface, has to be built right in front of them. To allow building with even better accuracy, we look to the cutting edge technology within the field of Mixed reality. Mixed reality equipment allows the user to see the blueprints in the exact position it is supposed to be built.

Innovation in construction

The world of construction is slow when it comes to adapting to change and innovation compared to other industries. This is because it is one of the largest industries, and often the largest objects require the most pull to be moved. That is why my external supervisor Øyvind Svaland has gathered several leading Scandinavian contractors to help evolve the mixed reality equipment that exists in this industry. He has got a saying on why new technology often doesn't catch on in this domain. The reason new technology has a hard time adapting is because the project always finishes in the end anyways. Which is true. But this view does not take into consideration the potential to increase efficiency, safety and profit into account.

To get to the point of raising skyscrapers, the evolution of construction has evolved through our human ability to create and utilize tools in order to accomplish our goals. In the next chapter we will get to know these tools & technologies and how they have evolved over the years leading up to the use of the Mixed Reality technology that we see emerging today.

Chapter 3: Emerging technology

Chapter Introduction

This chapter looks at HCI in the field of mixed reality to establish the relationship between the two. This will lay the ground for the description of augmented reality tools in construction and how they are interacted with from an interaction design perspective. The goal of the chapter is to give the reader an understanding of what mixed reality is, how it can be interacted with, and how it works so that the reader can follow along as we look at immersion theory in the next chapter. With this knowledge the reader will have a better understanding of how the accuracy of constructional work can be improved by the aid of MR technology.

Human Computer Interaction

The field of *human computer interaction* (HCI) is as we stated in the introduction the result of exploring the relationship between humans and computer input. Research in HCI focuses on the design of computer technology in a way that considers how humans interact with the technology and how to best do it.

HCI has since its debut in the 1980s when the first personal computers emerged as a natural aspect of developing technologies. Intelligent systems require intelligent user interfaces that are easy to understand for intelligent beings.

As mentioned, HCI applies to countless more complicated devices other than the personal computer. Digital technology is used by the majority of people living today and a lot of us utilize some sort of gadget to aid us in our daily tasks. This could be as a product developer for a phone company where innovation is important to sell. It could be a heart surgeon prototype testing augmented reality equipment for heart surgery or wearables such as a smartwatch to track your pulse. These gadgets come in many various forms from various companies. HCI was in the beginning a catalyst for familiarizing regular people with new technology, now it is a necessity and of the utmost importance in innovation.

This input can be by keyboard, mice, voice, touch, ink and movement through Kinect skeletal tracking. Now we see the dawn of environmental input, which captures the position of a person in the world (head tracking), the surface environment and boundaries in it (spatial mapping and scene understanding), environmental sound, ambient lighting, object recognition, and location all help to push the field of HCI forward. These are highly immersive technologies. Immersive technologies are technologies that allow you to delve into a digital world where your natural senses are being stimulated.

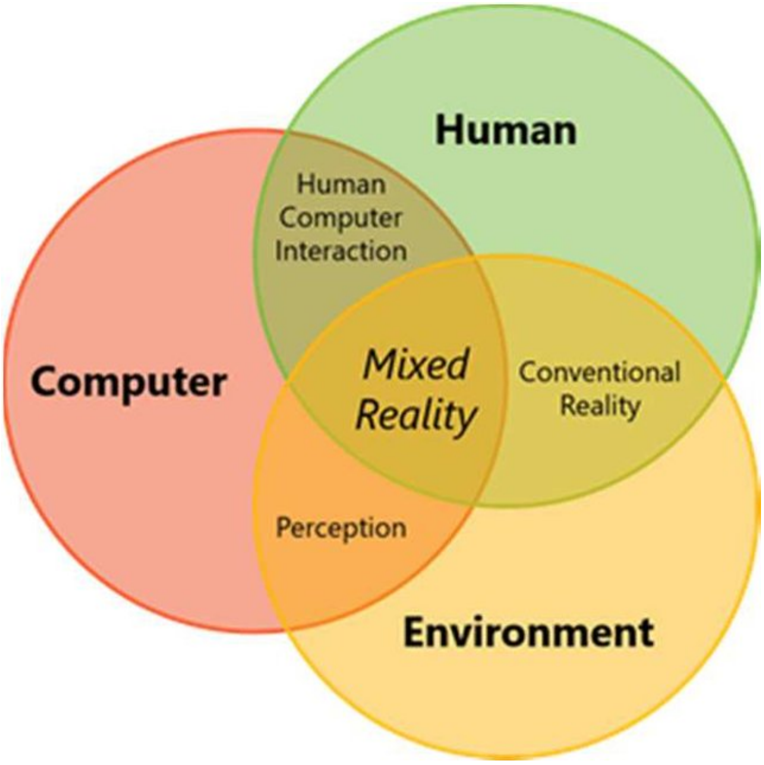

Figure 11: Computer, humans, and environments
(Human-Computer-Environment Relationship, 2018)

We were introduced to figure 11 in the introduction of this thesis. It represents the construction site (environment), the worker (human), and here the AR tool that is being used (computer). Environmental inputs are other workers and machinery operating the construction site.

With the help of all these new environmental inputs, movement in the physical world can also be movement through the digital world. Walls and surfaces in a physical room can become obstacles that influence the experience of a digital experience in the digital world. Thus mixing realities. (Microsoft, 2020)

Figure 12: Reality-virtuality continuum (Milgram et al, 1994)

Figure 12 illustrates the reality-virtuality continuum, which is a concept first introduced by Paul Milgram in 1994. Here, our physical world is represented on the left and on the right we have the digital reality. AR is on the left side, where we still find ourselves in the real world with elements added from the digital world (Milgram et al, 1994). Such as seen in figure 12.

These concepts are presented so that we have a common understanding of the levels of immersion mixed reality technology can supply. This is in order to lay the base for discussion of what levels of immersion benefits construction the most.

Humans understand and process visual data faster than text. 90 percent of the information that is being transmitted to the brain is visual information (Eisenberg, 2014). In the case of construction, seeing a real life sized holographic model of the construction that is about to be built, will help the people involved grasp a better understanding of the construction faster than a 2 dimensional drawing would. This removes ambiguity, thus improving accuracy. Improving the precision of construction leads to less error, which makes it safer, saves money and finishes faster.

As its name suggests, Extended Reality mixes the physical and digital world to allow interaction between computer, human and environment. Paul Milgram and Fumio Kishino were the first to introduce the term in the 1994 paper “A Taxonomy of Mixed Reality Visual Displays”. In the paper they explore the first concepts within Mixed Reality, the virtuality continuum and the appliance of categorization of taxonomy on displays. Even though this was designed for the technology and displays of the 1990’s, they are still useful since XR still encompasses environmental input, spatial sound, and locations and positioning in real and virtual space. (Milgram & Kishino, 1994)

Tangible user interfaces

A tangible user interface (TUI) is an interface that a person can interact with through physical movement. It was in its early stages called Graspable User Interface, but as Graphical User Interfaces share the same acronym it could cause confusion. A TUI seeks to give physical form to digital information, giving the human the ability to interact with data through grasping and manipulating objects with natural human abilities. These natural human abilities are movement of the hands, touch and other bodily movement.

Developers of MR devices have been focusing on this for a long time. Some VR headsets come with hand controllers that can grasp and utilize objects in the virtual environment. Now Microsoft HoloLens 2 introduces holograms that can be physically interacted with without the need for hand controllers. It does this by spatially mapping your hands.

TUIs are made up of tangible and intangible elements. The intangible elements are information such as graphics and sound. The tangible elements are physical objects that one can grab and manipulate. (Gulbrandsen, 2020)

This shows how far MR technology has come. We will now look at how newer devices should and some do allow natural movements. This is important because if it is to be used in aiding practical challenges, it has to allow the user to perform natural movements. Not to restrain the user. Therefore, MR equipment is being judged by the 6 degrees of freedom.

Degrees of Freedom

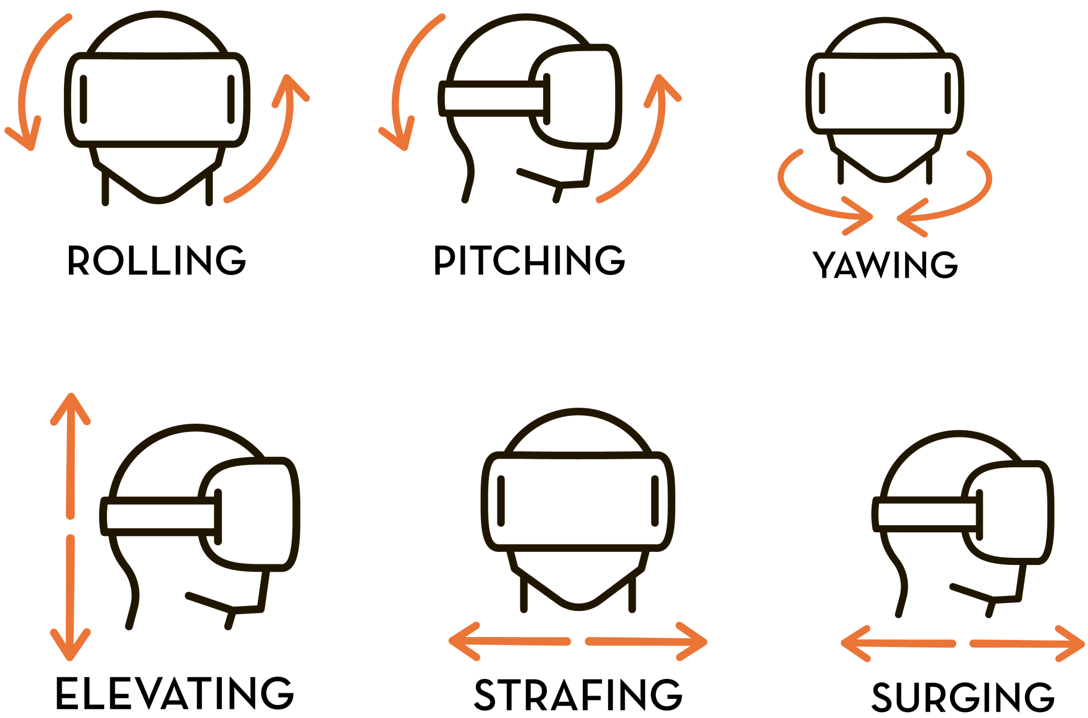

Figure 13: Visualizing the 6 degrees of freedom when using XR equipment.
(6 degrees of freedom, 2021)

Rolling: Moving your head side to side
Pitching: Tilting head along vertical axis
Yawning: Looking left or right
Elevating: User moving up and down in space
Strafing: User moving left and right in space
Surging: User moving back and forth in space

“Degrees of freedom (DoF) refers to the number of ways a rigid object can move through three dimensional space. There are six total degrees of freedom which describe every possible movement of an object.” These six degrees are illustrated in Figure 13. The top three in the figure are movements where you tilt the device in order to know if you are looking up or down, to the sides and around you or a combination of both at the same time. The last three movements are to register where you are spatially. If you're moving backward, forwards, left or right, up or down. (Bernard, 2019)

Most VR devices now support 3-DoF or 6-DoF. With the introduction of Microsoft HoloLens 2, AR also supports 6-DoF. Trimble Sitevision supports 3-Dof (elevating, strafing and surging). Registering the position of the user, allowing the user to move through the digital world in real time. Which in many cases is enough to aid in certain tasks, as we will see in the attached evaluation.

It is important for head wearables that are to be used in real world environments to support all degrees of freedom. If the user is restrained by the abilities of the technology while wearing it, it could dampen the user's primary senses and endanger the user or distract the worker by not having the GUI follow the line of sight. During work this could cause distractions and cause annoyance to the worker, resulting in the neglectance of the technology.

Human Perception

Mixed Reality technology has had to tackle problems regarding resolution and human perception. For wearable devices such as the HoloLens 2, presenting high resolution holograms right in front of your eyes became a challenge. The first HoloLens offered a field of view that was 30° horizontally. The new iteration doubles its field of view.

Each of our eyes has a field of view of roughly 160° horizontally and roughly 175° vertically. The binocular field of view is the effect of both eyes working together stereoscopically to perceive depth. The binocular field of view for a human is about 120° horizontally and 135° vertically.
The central area of focus is about 5-7°, our sharp sight is about 5°. Everything outside of this scope is called the peripheral field of vision.
Hertz is the unit of frequency that is defined as one cycle per second. Human perception allows us to view it as the amount of times the picture in video updates per second. If a source of light flickers lower than about 60Hz, most people will experience a flickering image, but higher frequencies are experienced as constant light. (Gulbrandsen, 2020) This means that even the most advanced AR technologies today can only cover 37,5% of our full depth of view. Which has an effect on the immersion one experiences. This is enough to aid the worker in solving a task. It does not directly say anything about the amount of immersion that is being displayed as that depends on the software, but it limits the effect of

it. Perhaps this is more than enough to display a beneficiary amount of immersion. We will look further into this in the immersion chapter.

Mixed Reality Equipment and Immersion in Construction

Immersion is of great importance when considering using mixed reality equipment on the construction site. We will delve deeper into immersion in chapter 4 and relate it to construction. To improve upon the technique of a master craftsman that has been on site the last twenty years, immersion has to be effortless, directly providing better accuracy for important jobs than the worker can. Creating great foundations for constructions becomes easier when assisted by a machine. This is a more advanced form of computer aided design than we have seen previously. With the help of live collision detection, the user can see when elements overlap right in front of them, and then be able to develop alternative solutions.

An example of this comes in the form of road work. When a crew is to lay piping beneath the ground, information of already existing groundwork is often scarce. This can cause the crew to dig up a bigger area than they have to because they are unsure of where the pipes are already laid. With AR markup, they could see this beneath the ground before they start digging. This would save time as they only have to dig where it is essential. Now, when they want to lay new piping, they can use AR to see where it can be laid, the extent of the piping and the potential adjustments they have to make to it in order to avoid collision with other pipes. This is live collision detection, which is already available in the technologies to be presented.

Trimble SiteVision

Trimble SiteVision is an outdoor augmented reality system. As seen in figure 14, the physical part of the system appears as a handheld device that features a handle, a phone mount and a centimeter accurate Global Navigation Satellite System (GNNS). With this, you can turn your phone into an Augmented Reality BIM coordination machine.

Figure 14: Trimble SiteVision user interface, a handheld Augmented Reality device (Sitevision.Trimble.com)

Functionality

Trimble SiteVision can display 2D and 3D data accurately placed and real life sized into the real world environments from any angle to the point of 1cm accuracy according to Trimble. (Sitevision datasheet)
This is possible because the GNNS system allows the device access to additional satellites, which helps the device become more accurate than by only using GPS. (Hedmond ,2020)

According to Hedmond, the system also has the ability to log clashes and omissions, assign tasks to workers, take quick measurements, georeferences pictures and measure grade and cut/fill.

The hardware includes the Integrated positioning system, sunshade, 2 Swappable batteries, a carrying case, a pole mount, an USB cable and a battery charger.

It's system software works with 3D modeling softwares as SketchUp, Revit, and AutoCAD. The system is only available and can be used on Android phones that support AR. (Hedmond ,2020)

Trimble Sitevision is currently being used on several construction projects around the world to overlay BIM models onto the jobsite where it helps the users get an understanding of the scale and aesthetics of the building. It does this by displaying a 2D or 3D model, that is true to scale and accurately placed by location. (Hedmond, 2020) As we mentioned, it supports 3 degrees of freedom which allows the user to spatially move around and within the model to take a close look at the elements through the user interface.

Trimble Sitevision User Interface

TSV displays holographic images on top of reality through the mobile screen in order to help the builder and engineers build with better precision. The description of the figure holds a guide to all the buttons and widgets of the layout to explain their usage. The interfaces widgets are placed on the site not to block the holographic images that are projected on the screen.

Figure 15: Trimble SiteVision GUI screenshot.
Symbol that shows GNNS status(1), symbol that shows orientation status (2), slider for view distance(3), hamburger menu (4), slider for cross section (5), applications menu (6), slider to adjust transparency (7), 3D/2D view selector (8), pit views (9), layers (10) (siteivison.Trimble.com)

Microsoft HoloLens 2

Figure 16: Microsoft HoloLens 2, an immersive Augmented Reality tool with tangible holographic images (Microfost HoloLens 2, 2021)

Microsoft HoloLens 2 is in the field of MR an important tool that has been included in this thesis to give insight into how far the technology has come and the potential MR has as a wearable technology. While the thesis' evaluation focuses on TSV, Microsoft HoloLens 2 will be used in discussion as it is an example of one of the newest and most complicated MR devices created so far.

The HoloLens 2 would have better immersion qualities than the TSV. The reason it is not being evaluated is that Veidekke, who has provided me with the possibility of evaluating a MR device, meant that the evaluation of TSV would give results and give value quicker. This is because Trimble has been a part of this project and Trimble are themselves developing TSV, while HoloLens is being developed by Microsoft.

The HoloLens 2 is cutting edge mixed reality technology that has inspired the invention of very intricate and complicated components to allow 6 degrees of freedom, a tangible user interface and a sharper quality in picture. The device will cost $3,500 for the hardware only, which rivals the pricing of Trimble Sitevision. Hardware Journalist Larry Dignan from Techrepublic says that: "The return on investment for the HoloLens is pretty simple: If you can use the device and remote assistant tools to keep one employee from traveling, you can recoup $3,500 quickly on the hardware costs. Efficiency and fewer errors in the field can also save time and money." (Dignan, 2019)

This shows how it benefits accuracy, cost reduction and how it will have an environmental impact as well by less travel. During the 2020 Corona Pandemic, being able to do check-ups and meeting remotely has been of great importance. The HoloLens 2 has the potential to put the user "closer" to the construction object from their own home or offices.

Compared to the first Hololens, comfort of wear has been improved. Now the device features better and lighter hardware, and a flip-up visor, so you can make direct eye contact without taking your wearable device off. you are also supposed to be able to fit your own glasses behind the HoloLens 2s glasses.

It is mainly developed and targeted at professionals rather than consumers. The product is for the front-line workers, those working directly with their hands. This could be mechanics, electricians, or surgeons.

As you put on Microsoft HoloLens 2, it logs you in with iris recognition sensors, that also enables eye tracking for the device.

Microsoft has added two Azure services that could be useful for the HoloLens. Azure is Microsoft's cloud computing platform. Cloud computing allows the device to do computation on an external server when connected to the internet. This lets the device perform data-heavy processes without carrying the hardware required to do so physically. These services are the ability to render a hologram at the same place in the real world across multiple devices. This can be done because the applications of HoloLens 2 can share spatial anchors between themselves. This means that a HoloLens 2, an Iphone and an Android phone user can use a shared coordinating system to be able to see and interact with the same holographic imagery through different devices and platforms. (Dignan, 2019)

HoloLens 2 Tangible User Interface

The HoloLens 2 allows the user to interact with the holograms by using your hands. It does this by tracking the movement and location in space for each of your fingers.

The principal group program manager for Microsoft Mixed Reality, Chaitanya Sareen says that their goal is to “make the machine work around the person versus the other way around.” They have chosen to call this “instinctual interaction” as an opposite alternative to “intuitive”. This is because it can get aid from the way we already interact with real world objects.
He mentions that most of the interfaces we meet are learned. you are not born asking “where is the close button?”. A goal that the team has is to use gestures you picked up as a small child instead of learning a completely new type of interface. (Bohn 2019)

The XR10, Microsoft HoloLens 2 x Trimble

Trimble XR10 is a combination between an industry standard hardhat that is certified for use in safety controlled environments and a Microsoft HoloLens 2.

XR10 allows you to effortlessly use HoloLens 2, as it is always with you for you to pull down and use. It supports tangible interaction with the holograms without the need for handheld controllers. AI eye tracking technology makes the holograms follow your line of sight. If you are reading a text, it will automatically scroll as you gaze downwards. Building construction models are given context when overlaid onto the real world enabling field workers and reducing errors. (Trimble, 2020 XR10)

Figure 17: Trimble XR10 combines Microsoft HoloLens 2 with a hard hat (Trimble XR10, 2019)

Chapter 4: Immersion

An Introduction to Immersion in Extended Reality

The goal is to have immersive technology that can help solve real world problems. It is already being utilized in many domains, as we will explore later in this chapter. Often when one thinks of immersion, it is within the domain of entertainment. Increasing immersion is the goal of diverse areas such as computer games (Calleja, 2001), film (Bazin, 2018, Kracauer, 1997), art (Grau, 2004), journalism (Sanchez Laws, 2019), virtual reality (Vindenes, ,music (Schrimshaw, 2017), literature and narrative theory (Koblizek, 2017), education (Oberdörfer et al. 2019), medical training (Satava, 1993), tourism (Blumenthal & Jensen, 2019), social communication (Gackenbach and Bown 2017), and therapy (Osimo et al. 2015). AR is different from Virtual Reality. In VR you are fully immersed in the technology and separated from the real world. We will focus on immersion that enhances precision. Thus in this chapter we will explore the degree of immersion that is productive for construction. Too much can be distracting and cause dangerous situations on the work site. Too little would make it of no use.

In order to enhance the precision of information for a worker, the level of immersion has to be enough that it communicates information to the worker that aids the worker in solving a task with better quality in a way that the worker can understand easily. If there is too strong immersive technology, the worker can be blinded by the graphical user interface, which is dangerous on a construction site.

Defining Immersion

Immersion as a term is vague in its definition. The terms presence and engagement have become interchangeable with immersion. In the domain of construction, presence and engagement is provided by the environment. Immersion here is the practical, visual and audible aid that is given to the worker through AR equipment. Combined with the skills and knowledge that the worker already has, the worker is able to enhance the precision of his work by having a virtual environment displayed on top of reality. This virtual environment provides guidance for the worker, such as where a structure is to be erected if you are constructing a building, or it could also be to display underground elements in their real size at their real position. This is so that a ground worker can know where to dig and where not to dig. Trimble SiteVision does this with the goal of eliminating ambiguity.

To seek to understand the vague term of immersion, scholars at the University of Copenhagen have done literature reviews of papers regarding the term and compiled it into a scientific article. (Nilsson et al, 2016)

In this article they present the results of their review as a three-dimensional taxonomy of varying definitions and conceptualizations of the term immersion. These three dimensions are split into three different definitions": Immersion as a property of a system, a subjective response to narrative contents, or a subjective response to challenge within the virtual environment." (Nilsson et al, 2016)

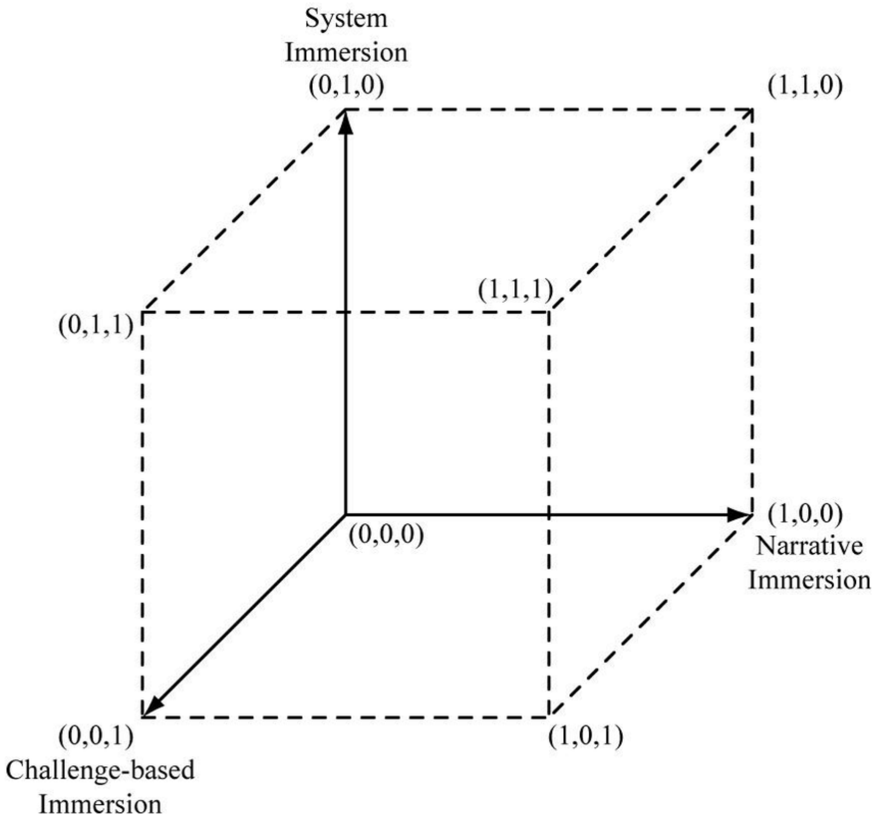

Figure 18: This is an illustration of Nilsson et als proposed taxonomy of the existing concepts of immersion. These three different axes that we have delved further into represent the degree of interaction with a system that involves system immersion (vertical), challenge-based immersion (depth), and narrative immersion (horizontal). This is represented on a scale from 0 to 1, where 0 is no immersion and 1 is high degree of immersion(Nilsson et al, 2016, p. 118)

The term immersion has become vague as it has been involved in many different domains of study such as video game, film, VE research, music and linear interactive works of fiction. It has also gained popularity with academic disciplines such as communication, cognitive science, engineering, computer science, psychology, the arts and philosophy. (Nilsson et al, 2016)

Nilsson and his colleagues at the University of Copenhagen adds a fourth category that is not directly included in the taxonomy by splitting immersion as a property of the system into: *"Immersion as a property of the system used to display the virtual world and immersion as a perceptual response to that system.* " (Nilson et al, 2016) These four categories encompass all definitions of immersion that the authors have collected, reviewed and categorized. This paper will focus on the types of immersion that are closest to the industry, technology and usage that this thesis focuses on.

All four categories and their definitions will be presented in order to understand how immersion to solve practical tasks can be separate from immersion in entertainment.. As Nilson et al (2016) mentions in their conclusion, these different explanations for each view should not be viewed as a source of ambiguity, but rather different ways for a user to interact with a virtual environment. The definitions that can be related to using AR devices in construction will be elaborated upon.

Four Categories of Immersion

Immersion as a property of the system

The first type of immersion we are to look at is **system immersion**. Nilson et al describes system immersion as: "A property of the technology mediating the experience. The higher the fidelity of displays and tracking the greater the level of immersion."(Nilsson et al, 2016, p. 111)
System immersion is different from the other definitions as it is used to describe the technology being utilized to immerse the user rather than the content the user is being immersed in. Such as the Trimble SiteVision

Immersion as technology. It has both been used to describe the technology a user uses, and what they feel when using it. Slater (2003) proposed that immersion is what the technology objectively delivers rather than the user's experience when being immersed in the technology.

Witmer and Singer (1998) argue that immersion could mean being in a psychological state where one finds themselves included in, enveloped by, and interacting with an environment that stimulates the user with continuous experiences. Elaborating further on this subjective experience of immersion, Singer (1998) presents three factors that this subjective immersion is influenced by. The degree one is separated from reality, a sense of feeling as a part of the proposed environment, and being able to act naturally with the environment through egocentric motion perception." (Witmer and Singer, 1998) TSV does not separate you from reality, but it still gives you a sense of being part of the proposed environment by looking through an electronic display. As mentioned earlier the three degrees of freedom, moving forward/backward, side to side and up/down lets you to some degree act naturally in the mixed reality environment.

Immersion as a perceptual response

Immersion as a perceptual response is described as a feeling of being included in, enveloped by, and interacting with the virtual environment you find yourself in.(Nilsson et al, 2016, p. 111)

It is defined as **sensory immersion:** "The sensation of being enveloped by the multisensory representation of the virtual world delivered via high-fidelity displays." or through large screens and powerful sounds. (Nilsson et al, 2016, p. 111) Achieving a high level of sensory immersion is a goal for virtual reality. TSV need only achieve a certain level of sensory immersion. To get a sense of scale and complexity.

It is also described as **Perceptual immersion:** "The sensation of being surrounded by the virtual environment that increases proportionally with the number of modalities provided with artificial stimuli." (Nilsson et al, 2016, p. 111) If you use more high fidelity equipment such as Microsoft HoloLens 2, you could find yourself surrounded by the virtual environment as it has a wearable display designed to make it feel like the objects generated electronically are real or realistic.

A response to narratives (communicative)

Immersion as a response to narratives is what we relate to reading a book or immersing yourself into a videogame that is trying to tell a story.

A description of immersion as a response to narratives is **fictional immersion.** In XR it is easy to think of VR as fictional immersion is defined as: “The sensation of being mentally absorbed by fictional stories, worlds or characters.” (Nilsson et al, 2016, p. 111) The definition fits the description of a good VR game or story, but has little relevance to completing useful tasks on site. The reason for bringing the term in is to because it is closely related to **psychological immersion.** Psychological immersion could be used to describe AR when combined with gamification principles . Psychological immersion is: “The mental absorption experienced during exposure to the world of a game’s story.”
(Nilsson et al, 2016, p. 111)

Gamification is the usage of game-design principles and elements in non-gaming contexts. An example of this could be to give points to the completion of tasks, badges for doing challenging work and leaderboards on the construction site. This could be fully possible with AR equipment, creating an imaginary narrative with extrinsic rewards on top of solving useful tasks. This would cross the reality-virtuality continuum, having the worker stray further from the physical world.

Rewarding the worker with gamified acknowledgement could potentially increase the workers satisfaction with completing a task, especially if one was rewarded with a name of a leaderboard. However, one could also argue that this could create a toxic work environment where there exists competition between the workers rather than synergy. Also if a worker is fed too much unrelated and gamified information together with the important and useful information displayed by the AR device, one could suffer from information overload. Information overload could lead to dangerous situations or simple irritations that would cause one to abandon the tool.

If one is to argue that immersion as a narrative could be applied to a construction site, gamification could be argued to create a false narrative that exploits digital extrinsic rewards. Pushing the definitions of immersion as a narrative this far is only a thought experiment that could not be concluded without experimentation. There is however another type of immersion that fits the description of using AR to solve useful tasks perfectly.

Immersion as a response to challenges (Instrumental immersion)

These definitions of immersion as response to challenge are directly involved in the case of using XR equipment as a tool in the construction business. It is not the equipment and the product of the immersive technology and its story that is supposed to be challenging, but rather it seeks to help solve real world challenges with immersive technology.

Systemic immersion:
Arsenould (2005) describes systemic immersion as “The mental absorption experienced when facing challenges that match one’s capabilities including the challenges involved when exposed to non-participatory media”. When one approaches challenges that correspond to their perceived skill in an activity of interest, a psychological state known as flow can arise. Flow is a psychological term discovered by the social psychologist Mihàli Csìkszentmihàlyi. It is described as a state of focused attention, where one has a loss of self-consciousness, yet you feel a sense of control as action and awareness merge. Easier put, it is when you are so consumed by your task that you forget about time and space. (Csikszentmihalyi,1997) This makes the experience of doing a task intrinsically rewarding. If immersive technology as a tool could help workers reach flow state regularly, productivity and morale could potentially go up.

Mcmahan (2003) refers to immersion as **engagement**, where he says that: :
“The state of focused attention on the game brought about by the desire for gaining points and/or devised a winning or spectacular strategy.” (McMahan, 2003) The engagement of a construction project could be to do the job as well as possible to gain reputation as a skilled craftsman and therefore credit your firm or yourself.

Strategic and tactical immersion is defined as “A state of intense preoccupation with observation, calculation, & planning or with swift responses to obstacles.”(Nilsson et al, 2016, p. 111)
Everyday a worker meets an obstacle on the site. A trained worker can reach flow as we mentioned. However, less experienced workers or an experienced one performing a new task, might not reach flow. By the aid of mixed reality equipment, the challenges can become lesser. This can be done by using data rendered models to showcase what to do in the task at hand. If a machine helps you calculate angles for cutting and shows you the

precise placement of an element, ambiguity could be removed from the task. By removing ambiguity, the worker can become intensely preoccupied with the task, and thus reach flow.

Challenge-based immersion:
Ermi and Mäyrä refer to challenge based immersion as “the feeling of immersion that is at its most powerful when one is able to achieve a satisfying balance of challenges and abilities.”(Ermi & Mäyrä, 2005, p. 43) They believe that the challenges will always to some degree apply to sensorimotor and mental skills. Ermy and Mayra believe that both sensorimotor and mental skills will more often than not be related to the challenge. (Nilsson et al, 2016)

Nilsson et al argues that in order for a challenge to be experienced as immersive the overlap between sensorimotor and mental skill has to be brief in order to avoid attentional overload. Another option is that the user is very good at one of the conditions, so that the user's attention span for focusing on a more unfamiliar challenge is spared for the second condition concluding that either one of the tasks should have to be automated, or it must be possible to switch tasks. (Nilsson et al, 2016)

In practise on the construction site, a worker can be very proficient with wooden construction, measurements and placement. But not as good at seeing the bigger picture of the project, or calculating the amount of material needed.
In situations like this, a worker could be assisted by an augmented reality device to take care of the computational and strategic tasks. The worker might not need help with the practical bit as it requires abilities he has perfected through years of work. Tasks he is able to perform without applying too much attention.
This could be the other way around too. If the worker is good with oversight and seeing the big picture, but struggles with measurement and placement. The AR device could assist him with that. This would create a fine balance of challenge-based immersion.

Lucid is used to describe something that is expressed clearly. **Lucid immersion** is “A state of intense absorption in the task currently being performed.” (Nilsson et al, 2016, p. 111) This closely resembles the flow state previously described. This does not however intend that one performs the task at hand with satisfactory results as one can get stuck on a problem and still be completely absorbed in solving it. Lucid immersion in AR could be to express clearly to the user what has to be done in order to finish the task.

Discussion

Now that we have established some definitions of immersion, a discussion will follow. This discussion will use previously established concepts and definitions from the text to explore the right level of immersion for AR devices in construction and the TSV.

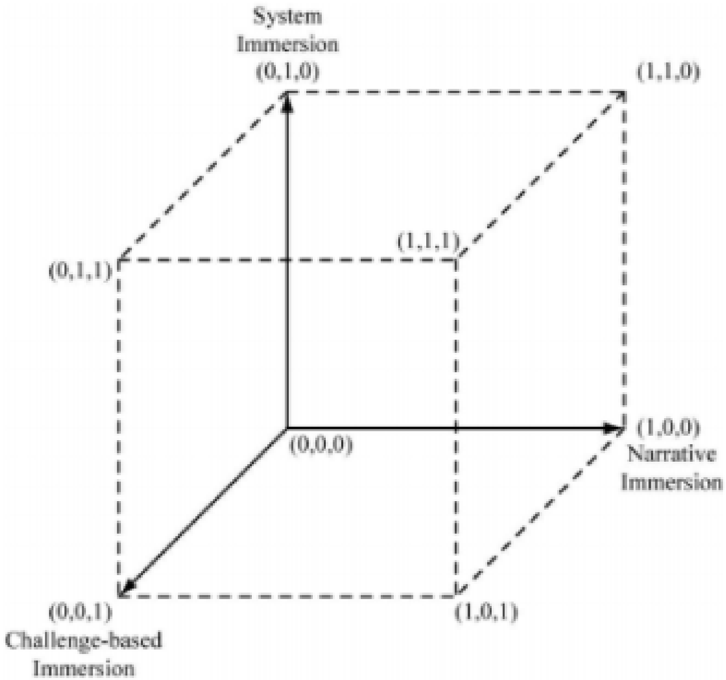

Figure 19: This is an illustration of Nilsson et als proposed taxonomy of the existing concepts of immersion. These three different axes that we have delved further into represent the degree of interaction with a system that involves system immersion (vertical), challenge-based immersion (depth), and narrative immersion (horizontal). This is represented on a scale from 0 to 1, where 0 is no immersion and 1 is high degree of immersion(Nilsson et al, 2016, p. 118)

This figure is a taxonomy presented by Nilsson et al to represent the three different categories of immersion presented in their article. Now after going through the different definitions presented, we can come to a decision that AR equipment such as TSV used as a tool in construction would range as 0,1,1 (top left corner) in their immersion taxonomy. This means that it mixes challenge based immersion with system based immersion as it solves practical challenges, but the degree of immersion is based on the system at hand. The system immersion merges the digital and the physical world with another,creating a mixed reality spectrum.

AR in construction is not supposed to be fully immersive. As in 1,1,1 on the taxonomy figure. This means that one is entirely separated from the real world. As perceptual immersion it increases proportionally with the number of modalities provided with artificial stimuli. As mentioned earlier, there is a big difference between Trimbles two AR devices as one is a handheld mobile AR device, while the other are goggles you put on that allow you to physically engage with the holograms through egocentric movement. The degree of immersion is limited by the usability needed and the system immersion. The system immersion is again how advanced the technology is for its purpose.

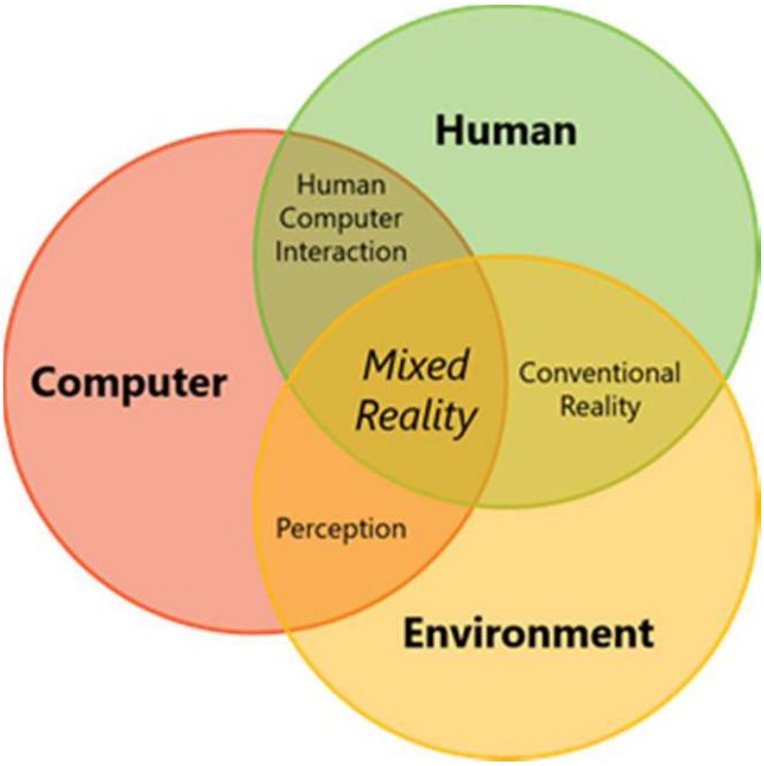

Figure 20: Computer, humans, and environments
(Human-Computer-Environment Relationship, 2018)

Again the relevance of figure 20 shows. The purpose of immersion when using AR equipment to solve useful tasks is different from when it is used for narration or gamification. If one is too immersed in the virtual environment of the construction site, dangers can arise as a construction site hosts many hazards for a worker. The degree of immersion has to be subtle enough not to envelope the user fully, but only to the extent that it assists the worker to complete tasks. In construction right now, where AR equipment is not yet a common tool on the site. The workers operate either with human - environment, computer - environment, or human - computer. These are not done at the same time. Human - environment is as put in figure 20 the conventional reality. Engaging with the task without the aid of immersive technology. Doing traditional carpentry for instance. Human - computer is the worker interacting with the computer program and its interfaces, going to the BIM kiosk to take a look at the 3D model that is being displayed on a 2D computer screen or tablet. Computer - environment is taking this information that one observed at the BIM kiosk and then take the computer generated model and manifest it into the real world. All these three different combinations are three different tasks that require the attention of the worker. By utilizing a fully immersed AR device, one could merge all these tasks. When the worker is familiarized with the tool, costs will go down as time consumption goes down since there are less steps to take in order to perform the tasks.

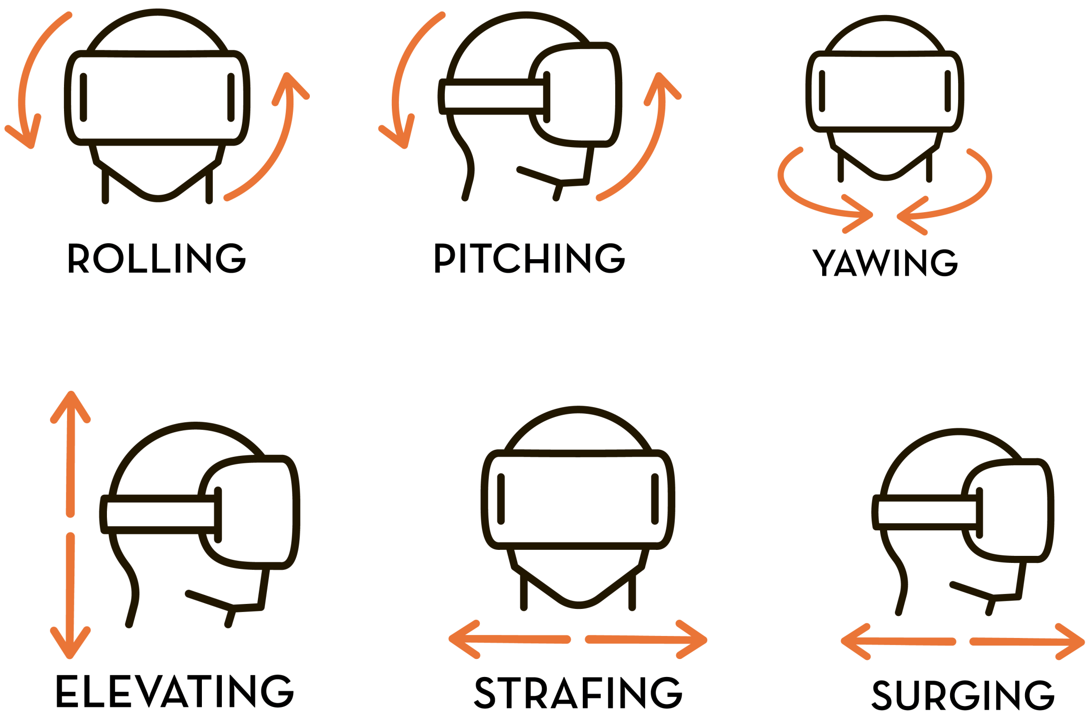

Figure 21: Visualizing the 6 degrees of freedom when using XR equipment.
(6 degrees of freedom, 2021)

Here again I want to talk about the 6 degrees of freedom. TSV supports elevating, strafing and surging. This could be considered the minimum degrees needed to give the user a feeling of immersion when walking about on a construction site. In the report, we will look closer at problems related to this presented by the interviewees. As it is a handheld AR device, there is no need for rolling pitching and yawning. However, a wearable device used for the same purposes, such as the Trimble XR10, does and should support all 6 degrees of freedom. This is because if the equipment is to feel immersive when moving about, performing tasks, it has to support natural movements without any lag to the graphical user interface. This could interrupt the immersive feeling.

Problems that affect immersion

We will also look at problems that negatively affect immersion. In the attached report there will be concrete examples provided by professionals. What we discovered here is that if things do not operate smoothly, create confusion or is in-consistent, the tool will be discarded by the workers.

As we have stated, challenge based immersion's goal should be to put the user in a state of flow that makes the task feel automated. However, if the equipment does not consistently work as it is intended, the worker will lose the flow state or never reach it at all. These types of irritations can easily lead to a seasoned worker returning to his traditional methods, which already works well for the worker. Some common problems that take away from proper immersion today are laggy equipment, slow loading, and configuration times.

Critical Discussion of the Technology

We have looked at benefits of using immersive technology in the field of construction, now we will consider drawbacks that could emerge by implementing mixed reality technology in construction. The implementation of new technology can be slow, but as new technology becomes the standard in an industry, a worker can become dependent on it. For such an immersive tool as we are discussing in this chapter, being aided in construction tasks can lead to deskilling (kilde).

Deskilling

Deskilling is when a skilled laborer in an industry is replaced with less skilled workers or new technology. Technology that automates processes that before required a certain skill or manpower to perform. A company might find that replacing a specialised worker with a less educated one or a machine, costs drop as they do not require the same amount of pay. A less skilled worker teamet up with new technology such as MR in construction, could perform well. However, it could also be critical when the system fails. If the AR technology aiding an unskilled carpenter fails, the worker would not be able to perform the job. This would then again slow the process and increase costs. In some cases the unskilled worker could try to perform the job anyway without the skills required, pushing the progress further back.

If anyone could do the job, there would be no need for much education as you are informed as you go by the equipment. For the modern day worker this is bad as we have mentioned as they might become overqualified. The industry could benefit from it if the equipment is good enough.
The end users of this Trimbles AR equipment are the workers that are on site. These are also the people in the corporation who have the least influence.

Immersion conclusion

In this chapter we looked at what type of immersion is fitting for the construction business. As we looked closer at challenge based immersion we saw that it was a good fit for solving real world challenges. Technology that satisfies these criteria would be extremely useful. We established that TSV supports 3 degrees of freedom, which is enough for its usage. We saw that there can be drawbacks such as deskilling by implementing AR devices on a big scale.

Chapter 5: Method

This chapter will explain the methods that have been used to gather data and how this data have been analyzed. Due to the covid-19 virus, user-testing on a construction site was not possible. Therefore expert interviews were utilized to gather information about the device and how professionals regard it.

From the methods used for data gathering and development, a report of the practical evaluation has been made to be useful for the domain of construction. This report presents 4 solutions to problems that have been identified regarding Trimble SiteVision. These solutions are a result of co-design, where some suggestions have been given by experts, then designed and evaluated by the cooperating parties.

Context of use and users

First I had to familiarize myself with who the user is and how they use this product. In this situation, the users are construction workers, managers and engineers out on site, using Trimble SiteVision to aid them in their daily tasks. To demonstrate I will present a use case.

Users and Use Case Trimble SiteVision

The user is anyone working on a construction site that benefits from viewing a holographic version of the project right in front of them. A use case could be a construction engineer that is the head supervisor of a road project where they are supposed to dig up the road to lay the groundwork for a new one. In doing this, the construction workers have to know if there is any important piping or wiring beneath the ground that they might damage if they just hack away. Therefore they have to consult the municipality to find information about what is beneath the ground and where it might be. This is time and cost consuming. If this information is not found, they just have to dig and see.
If this was to be marked with AR technology when built, one could utilize Trimble SiteVision to effortlessly “see through '' the ground where the pipes are accurately placed, such as shown in figure 17. This will be further elaborated on in the expert interviews in the report, where the subjects explain their experience with this type of case.

When interviewing the experts it is important to ask the right questions. As construction is a domain that I am not familiar with, I will make sure not to ask any leading questions. The questions are regarding frustrations and satisfaction regarding the use of Trimble SiteVision. This will lay the ground for follow up questions that can help aid in making changes in the design. The act of designing with your subjects and partners is called co-design. We will explore co-design further later in this chapter.

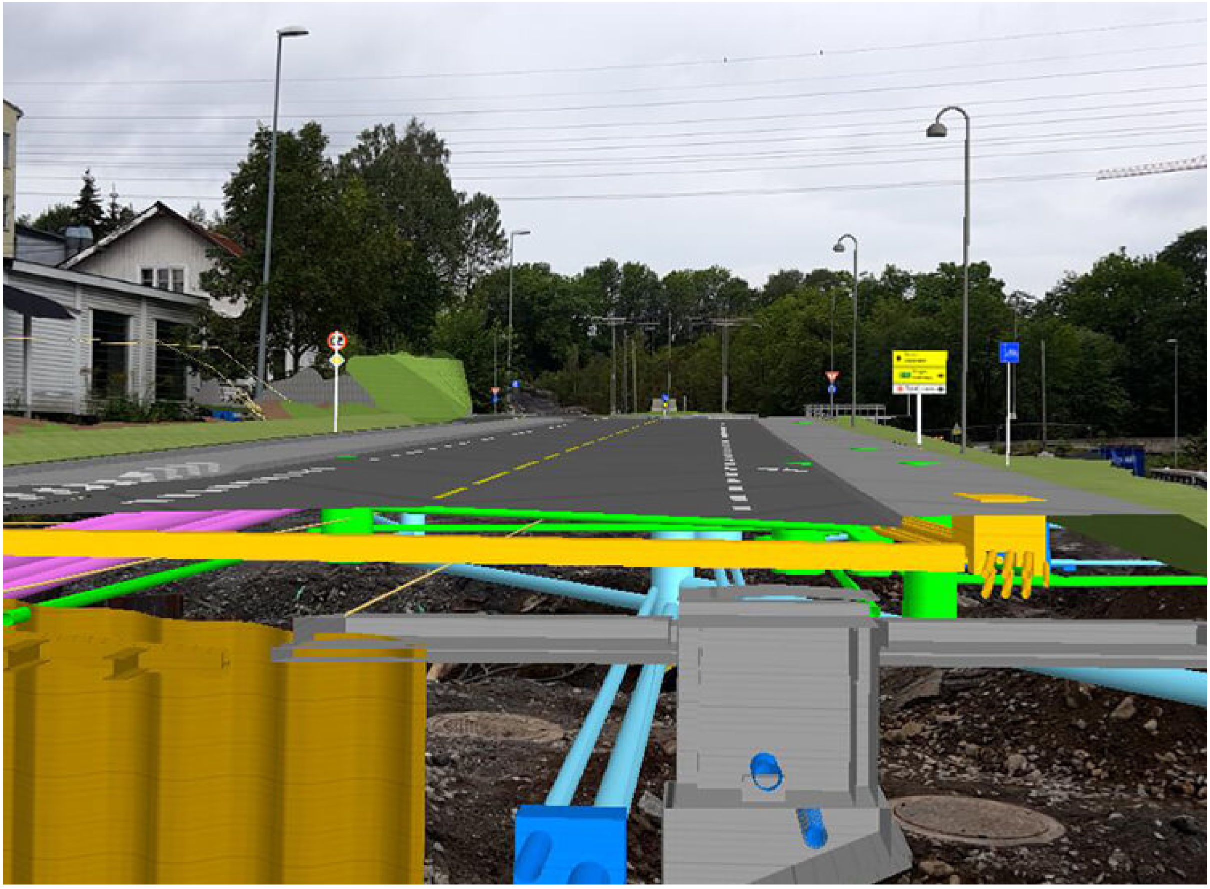

Figure 22: Trimble SiteVision, piping display
(Sitevision.Trimble.com, 2021)

Conversing with the subjects provided an understanding of the situations which require this design solution. From this, the team can look at what works well and what does not work well and together work on solutions that would benefit the business. These solutions are supposed to answer the questions of why certain functionality is working to its purpose, what is functionality that is not satisfactory, and how it should work. When the problems and potential solutions have been uncovered, it is time to start working on the design phase. Once it is done the team proceeds to the evaluation phase, where they evaluate the performance of the design to see how closely it matches up with the users' context and requirements. (Nordbø, 2017)

This project has the help of experts within the field of construction technologies, handheld augmented reality devices and media and information technology. Together with experts from Veidekke and Trimble, I have come to an understanding of the use cases of Trimble SiteVision and gathered the information needed by conducting expert interviews. These expert interviews were used to gather intel about various processes in construction that can be improved upon by using SiteVision and how SiteVision might meet this criteria.

Expert Interviews

Expert interviews are a qualitative method of data gathering where the interviewee is an expert in the domain that is being studied. Expert interviews could be one-on-one or in a bigger group. The reason for using expert interviews is that the problem that is being examined is a complex one that requires domain expertise, which is knowledge in the area of construction technology. (Underwood, 2021)

Using expert interviews can give you insight and understanding in how this equipment is being used and what the genuine consensus is, what other types of technologies are developing in the field, what is good and what needs to get better. Unintended intelligence is often a result of expert interviews as experts tend to go beyond the scope of the questions when being inquired about technologies in their field. Also, these experts are valuable contacts for future research. (Underwood, 2021)

As these are some positive traits of expert interviews, there are downsides as well. If your questions are not formulated well enough or you are not well informed you risk asking biased questions, which could weaken the value of the information you are about to collect. Some experts might have ulterior motives themselves that make them biased. Maybe they are stuck in the past and don't like innovation. Therefore they give you bad information. These are alle drawbacks that can be avoided with proper preparation and careful planning. (Underwood, 2021)

In this thesis, these experts are engineers and workers in the construction business with hands-on experience with the Trimble SiteVision equipment. Expert interviews are useful because they give high quality insight into the discipline one is studying, it's shortcomings and possibilities. Including the experts from early on is necessary to ensure that one understands the users of the technology. Some of these experts will be closely involved in the solution making process by a method called co-design which has been actively used to develop solutions presented in the report.

The interviews were conducted on Zoom, recorded and compiled into the practical component of the thesis, the report. The report is then structured and designed such that information is easy to find and easy on the eyes so that it will be intriguing for the construction professional to read. The first iteration of the report was then reviewed by Øyvind Svaland from Veidekke and Anders Høie from Trimble.

Co-design

According to McKercher, co-design is to design with people, not for people. She says that it works best when professionals, communities and people with lived experience come together to better something they all care about. This is very much the case in this thesis. All the stakeholders that have been involved are very much interested in improving this technology from both personal and professional interest.

In this project, these stakeholders are Anders Høie from Trimble and Øyvind Svaland from Veidekke. Trimble develops and sells the technology and Veidekke buys and utilizes it. They have been included in every step of this project by weekly meetings to make sure that we are always on the same page. They have aided by providing access to tools, software, experts and sending me illustrations, screenshots and videos. The experts that I have interviewed have also supplied illustrations, pictures and videos.
The reason for choosing co-design is that today, developing complex tools to solve complex problems requires competence from multiple disciplines. Øyvind from Veidekke speaks on behalf of engineers and craftsmen in the world of construction, while Anders from Trimble helps us keep focus on what is possible with their technology. (Co-design, 2016)

The book Beyond Sticky Notes by McKercher. K. A. Lists 4 principles of Co-design:

1. Share Power

It is important to share power so that the participant with the most acknowledgement in his/her field doesn't end up unconsciously gaining the most influence.

2. Prioritise relationships
   Social connections and trust between the co-designers and funders are important as one has to be able to speak their mind without being afraid of being judged.

3. Use participatory means
   Instead of just using the co-designers as participants, you should include them as active partners.

4. Build capability
   In codesign, everyone has knowledge that could benefit the other. It is always better to support each other and help each other learn.

(McKercher, 2020)

In a design development process, co-design can be utilized at every point. It is however beneficial to include other perspectives early on and regularly to figure out what the real problem that is being solved is early on. Including end users and the developing company can be challenging and messy without proper guidance, but with synergy, informants become participants, partners and contributors that might heavily influence your outcome in a very powerful way. On the other hand, including more people in the design process can slow it down by generating disagreements. This could also be a positive, as you the designer could get stuck on your own, only being driven forward by the insight of your co-designers. (McKercher, 2020)

The demography of the user depends on the project. In IT it would be beneficial to involve an end user and perhaps a developer. In health, it could be a patient of what you are testing and a doctor. To utilize co-design to its fullest extent, you want to include different people and organizations to gain an understanding of the full picture. (McKercher, 2020)

The process of co-design is according to McKercher design-led and focused on creative participatory methods. Methods such as expressing one self visually, orally, or with kinaesthetics instead of plain text, slides and reports. Co-design methods are not about reporting, it is about discovery.

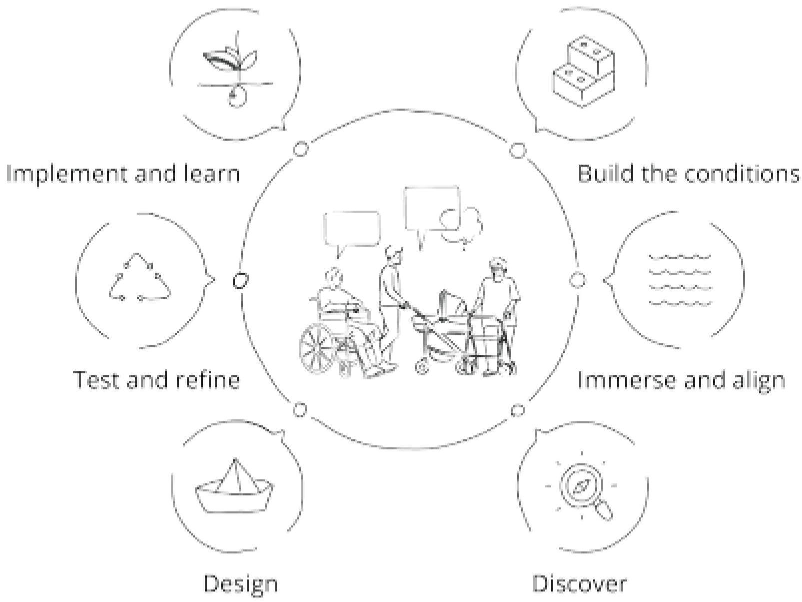

Figure 23: Process for Co-design (McKercher, 2020)

McKerchers provides us with a figure that visualises the co-design process. Together with the stakeholders of this project, we decided the conditions. That TSV was to be improved. In order to help me learn the domain, Høie and Svaland shared their knowledge and provided the expert leads to help immerse myself into the domain. The Discovery phase was doing the expert interviews. Semi-structured interviews that allowed the experts to provide solutions, and had us working the cases we discussed together. This led to a design. The design was then workshopped by myself, Svaland and Hoie. The next natural step would be to implement.

To conclude, co-design is a good method for reaching a design solution that all participants find satisfactory and that has a big certainty of being useful in the end. It can on the other hand be tricky, as opinions can clash and squabbles take up valuable time. As the world becomes more complex and people become experts in unfamiliar fields, it is important that stakeholders work together interdisciplinarily.
(McKercher, 2020)

The Practical Component: The report

This part of the chapter explains why there is a separate report attached to this master thesis. It is inspired by the structure of the master thesis report in Media and Interaction Design from 2020 “Fra Strømmetjeneste til Drømmetjeneste; Dette må du vite for å lage en strømmetjeneste for barn”. (Jensen, F.H et al, 2020)
The group of three master students who wrote this, each developed an academic component for the university and together created a report that can be easily read by TV2 and other interested parties. The report is straightforward and has a clear purpose in informing TV2 about the results of their research.

This project has adopted a similar approach. The evaluation has gone through many iterations where it has been evaluated together by me, my supervisor Lars Nyre and my two external contacts, Øyvind Svaland and Anders Høie. We have had annual meetings where we share ideas and I receive feedback. This has allowed the report to go through a process of validation, validating that it is indeed becoming useful to end users as Øyvind is an end user. .

The report that is the practical component is angled towards professionals working in Veidekke. It is to be presented sleek in design with the contents being useful to the reader. It mixes interaction design with a classic report. The purpose of this is to make it easily readable and interesting, including language that can be understood by the reader while presenting the results of my studies. This will enlighten the readers about the field of interaction design, augmented reality and its relevance in their domain.

Conclusion

In this academic text we have looked deep into the immersive technology of augmented reality and how it can be applied to the business of construction. We have looked at human computer interaction and how it relates to immersive technologies. With it we have gained an understanding of how one can design for better user experience for AR technology users that seek to solve instrumental and useful tasks.

We discovered that when designing for AR devices, it is important not to overload the user with information so that the user becomes distracted. To display only what is necessary for the worker to perform the job with better precision than without the tool.

The practical component has shown that it is important to include users and experts of the domain that is being studied in order to reach a useful result. Expert interviews coupled with co-design works well as it allows you to closely cooperate with experts in the field and gives you the possibility to talk to various experts.

Summary

This thesis started out by familiarising us with the term instrumental immersion within our scope. That is, solving useful tasks with the help of immersive technologies. In our case: Augmented Reality. Then we were introduced to the domain that the technology is being researched within (construction) and the specific equipment being used (Trimble SiteVision). To be able to evaluate this device, a knowledge of UX was presented.

To give the reader insight in the domain of construction, tools for construction were presented to lay the groundwork for how we got to the point of using AR. Important tools such as the total stadion, computer programs such as CAD and BIM have are all important to understand to get an understanding of the tools that the engineers and workers in construction work. This helped a lot during the expert interviews.

Chapter three looked at applying HCI principles to immersive technologies. It also presented the six degrees of freedom that are achievable with mixed reality equipment as well as introducing the relevant equipment for the thesis and taking a in depth look at TSVs user interface.

The concept of immersion was explored in chapter four. Here we explored different types of immersion to see what best related to instrumental immersive technology and landed on immersion as a response to challenges. To be able to use the technology to better the precision of instrumental processes and remove ambiguity in digging, positioning and other constructional processes.

The final chapter presents the methods that were used in this thesis. This was the expert interview and co-design. These were used to create the practical component attached to this project and the expert interviews are included in the report that is the practical component.

Further research: TekLab

For further research in the field of Mixed Reality at the University in Bergen take a look at TekLabs research at https://teklab.uib.no/.

Limitations

Due to the 2020 covid-19 pandemic, user testing was not done as intended. It was originally intended that I was to do usertesting in the field together with users. Because of the pandemic, it was not possible for me to join the workers on site. Therefore expert interviews were used instead.
Because of logistic issues within Veidekke, I was not able to get my hands on the device known as Trimble SiteVision myself. My experience with the device came second hand from speaking with users, watching videos and reading manuals.

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