Integration of Digital Twin to Augmented Reality in Industrial Enrichment Plants: An Anticipated User Experience Study

University of Oulu
Information Processing Science
Master's Thesis
Juho Toratti
2022

Abstract

Understanding user experience is necessary in developmental phases of every service, program and system. However, when adopting new technology, the early developmental phases methods and metrics used in user experience are not sufficient in anticipation of situational use and use cases of users. Therefore, focus and perspective to anticipated user experience research early in the development phase is needed. These problems are also true in ubiquitous computing field of Industry 4.0 where human computer interaction is in constant flux. New types of technologies and solutions are emerging and constantly seeking ways to capture their market share, bring added value or to revolutionize the industrial field without first understanding the anticipated requirements. This is true also for different industrial process control applications like digital twins and ways that augmented reality could be utilized in the on-site and monitoring operations.

This thesis determines what the anticipated user experiences are for the professionals working in the industry and how applications can be integrated to augmented reality in industrial contexts. To tackle this issues artifact and gamification as design method will be utilized. Anticipated user experience study approach is applied and combined with early developmental artifact in the interviews. Research data is collected both qualitatively and quantitatively, but the main research method and data analysis is implemented with qualitative data.

Contributions of this thesis is to determine if the use of early developmental artifact helps with the anticipations of user experiences and use cases for new technology adaptations to augmented reality in industrial contexts. This thesis proposes the term *artifact specificity constraint* and contributes to a model for converged relations of virtual reality continuum and digital twins. This thesis outlays a coding scheme with nine categories to be used as a reference for similar focused research.

Keywords
Anticipated User Experience, Augmented Reality, Digital Twin, Gamification, Industry 4.0

Supervisors
PhD, Paula Alavesa, PhD, Leena Arhippainen (University of Oulu)
Technical supervisors PhD, Antti Remes, MSc Piia Alavesa (Metso Outotec)

Papers to be submitted

Alavesa, P., Alavesa, P., Toratti, J. (2023) Designing gamified interfaces for a process digital twin in mining context through a series of expert workshop. To be submitted to *GamiFIN* Dec. 2022.

Toratti, J. & Alavesa, P. (2023) Using anticipated user experience on early development phases of Augmented Reality applications in Industry 4.0 technologies. To be submitted to *Augmented Humans*.

Foreword

First want to acknowledge the financial support, funding and the opportunity that Metso Outotec gave me to make this thesis project and research possible. This research project allowed me to conduct research on a topic which would have not been possible without the combined collaboration of Metso Outotec and The Center for Ubiquitous Computing (UBICOMP).

My heartfelt thanks and praise to all my supervisors and reviewers. I thank my official main supervisor PhD, Leena Arhippainen, and the reviewer PhD, Mikko Rajanen from the Information Processing Science, in the Faculty of Information Technology and Electrical Engineering (ITEE), University of Oulu. My utmost gratitude to PhD, Paula Alavesa, from The Center for Ubiquitous Computing (UBICOMP), ITEE, University of Oulu. I would like to especially thank Paula because your effort in supervising this thesis upgraded it to the next level, you gave me immense amount of valuable advice and every obstacle during the research process were overcome with ease. The continuous support you gave really made this thesis possible and I could not have wished for a better supervisor. Thanks for Asst. Prof., Minna Pakanen for comprehensive collection of research related to anticipated user experience.

I would like to thank my technical supervisors PhD, Antti Remes and MSc Piia Alavesa who acted as my second technical supervisor from Metso Outotec for all the help and guidance during the writing and research progress. Piia thank you for always helping and guiding me with the designs and for facilitating the project workshops. Your guidance and help with my thesis made it feel that I had four supervisors. Special thanks also to Jari Moilanen, Jani Kaartinen and Johanna Kortelainen from Metso Outotec. Thanks to all the people who spent their valuable time and took part in the interviews and workshops. Having the ability to conduct qualitative research with the actual potential users was wonderful and unique opportunity.

Thanks to my family and friends for supporting me during the whole research process. Especially Elina, Pirkka-Pekka and Toni thank you all for never doubting me even when I doubted myself. Thanks to Ville S. for thesis writing compassion, it had a positive effect on my motivation to share the writing experiences with you.

Thanks to Datadrivers Oy for the infinite amounts of coffee I could consume during the writing process and to my coworkers from there for providing me a friendly and familiar office environment to author this thesis in.

Oulu, December 9th, 2022

Juho Toratti

List of abbreviations and symbols

2D	Two Dimensional
3D	Three Dimensional
AA	Artifact Application
ACT	Advanced Process Control
AUX	Anticipated User Experience
AR	Augmented Reality
ASC	Artifact Specificity Constraint
CAVE	Cave Automatic Virtual Environment
DT	Digital Twin
DOF	Degrees of Freedom
FOV	Field of View
FPS	Frames per Second
GDT	Geminex Digital Twin
HAR	Handheld Augmented Reality
HCI	Human Computer Interaction
HMD	Head Mounted Display
IT HUD	Heads-Up Display
KPI	Key Performance Indicator
LIDAR	Light Detection and Ranging
MAR	Mobile Augmented Reality
MR	Mixed Reality
OST	Optical See-Trough
PG	Pervasive Game
POV	Point of View
RE	Real Environment
SLAM	Simultaneous Localization and Mapping
SR	Serious Game
UI	User Interface
UX	User Experience
VE	Virtual Environment
VST	Video See-Trough
XR	Extended Reality

$\bar{x}$	Arithmetic Mean
κ	Cohen's Kappa
σ	Standard deviation

Contents

1. Introduction

As Industry 4.0 is becoming more common, there is a demand for pervasive applications that can simultaneously react to dynamic market-driven economics and adapt to real-time information to stay competitive and relevant in the field. This is relevant also in material manufacturing and enrichment industries as every system in the materials manufacturing process must be simultaneously predictable, accessible, optimized, and efficient. For this reason, industries need a medium between real-time virtual representation, integration, and gathering of real process data derived from hard and soft sensors used in the process flow. This data can then be used in parallel with the manufacturing process to run simulations respective to their processes. To solve these challenges industries have started to use concepts based on Digital Twin (DT) technology. DTs are a virtual representation of the real manufacturing systems, spaces, or components present in the systems. With the help of DT data gathered can be used to represent numerical and textual data, Key Performance Indicators (KPI), product 3D models, and resources present in the virtually mirrored real-time processes. For these reasons also Metso Outotec has developed a digital twin (DT) web application *Geminex* Digital Twin (GDT). With the goal of predicting real material enrichment processes to save time and materials and provide KPI-based autonomous decisions while simultaneously allowing the real manufacturing process to run.

Running simulations and using a web application-based user interface (UI) can be a tedious and monotonous task for the operator tied to the control room or office environment, which may lead to user disengagement and poor quality of user experience (UX). To increase user motivation, and engagement, and to provide a positive experience with the GDT application, gamification: a design method that uses game elements in non-game contexts is introduced. For true engagement and release from the spatially restrictive web application UI, the GDTs could possibly be integrated into augmented reality (AR), where the merging of the real environment (RE) and virtual environment (VE) is possible.

The purpose of this research is to introduce and anticipate needs, expectations, and potential use cases for integrating traditional and simulation web application GDT into AR, while discovering the user's feelings, experiences and that emerge towards the technology. The anticipated user experience (AUX), feelings, questions, and opinions will be researched and evaluated with the help of an artifact and an interview with open-ended questions. Before the implementation of the actual AR artifact, there was a need for AR integration with the current UI and UX of web GDT at the request of Metso Outotec. The current application will be thoroughly evaluated and assessed in workshops to identify functionalities or designs from the system in need of a re-design. After identifying the parts new UI/UX designs were implemented using gamification as the main design method. After the presentation of the new layouts, an iteration and evaluation period was conducted which resulted in finalized UI layouts. These layouts were then implemented into the system, and they worked also as the basic design guidelines for the artifact application (AA).

1.1 Motivation

My motivation for this research comes from a particular interest in producing designs and solutions for UX and UI that simultaneously helps the user, increase profitability and technologically develop and break traditional work norms in real work environments. The basis for this motivation is laid by my personal interests in the work applicability of extended reality (XR), video games in general, and how gamification can be utilized in work environments.

My interest in XR really deepened when I studied the special courses in computer science and engineering (CSE) provided by the University of Oulu. The courses ranged from 3D environments, extended realities, and virtual reality systems to humans and digital fabrication. These were my favorite courses and sparked my interest as an information process student to move into more ubiquitous computing and CSE-oriented studies. Excellent grades from these courses allowed me to gather the competence to apply and be chosen for this CSE thesis project. With the opportunity provided by Metso Outotec and UBICOMP Oulu (Center for Ubiquitous Computing), I had the opportunity to research a subject that was perfectly suited for me.

1.2 Method and research questions

This research was conducted by utilizing mixed-research methods (Williams et al., 2007). The priority method of data collection is qualitative and quantitative data acted as a support. Anticipated user experience evaluation is used as the study's evaluation method. To find potential utilizations of technology and UX in very early development phases of applications, it is helpful to include an artifact or a visual design example into the interview process (Yogasara, 2011; Pakanen 2015). Olsson (2014) noted that a problem persists when less experienced participants participate in AUX studies. These participants have a harder time imagining for future uses of a technology which conflicts with their current one. For this reason participants chosen for the AUX study and evaluation methods were all professionals in the study's industrial context (Kukka, Pakanen, Badri, & Ojala, 2017). These choices made it possible to utilize and use AUX in this study as the evaluation method.

The data was collected using a semi-structured interview (SSI). Eight participants were interviewed, and the interview consisted of an artifact demo, open-ended questions, probing questions and additional support questions related to comfortability and safety. These additional questions consisted of Likert scale and word pairs. Likert and word pairs were used to gather additional data about the participants history with AR. The findings were analyzed using thematic analysis where the interview transcripts were categorized and coded and results were confirmed using Cohen's Kappa. Interviewees were chosen as a mix of industrial plant workers in Bulgaria and Metso Outotec experts working with the web GDT. Half of the interviews were conducted in Bulgaria and half in Metso Outotec Espoo office. This seeks to answer two research questions:

1. What are the fundamental requirements in an industry setting for adopting and integrating AR technology?

2. How can integration of applications user interface to AR be guided with AUXs in early development phase?

1.3 Author's contributions

The author was responsible on the design process of the software layouts and the artifact, creating, planning and development of the artifact, planning and conducting the study setup, 3D modelling in the presentation application. The author was also responsible for planning the research and conducting the interviews, data collection and data analysis.

1.4 Scope of the research

This thesis is a part of a large multidisciplinary field called human-computer interaction (HCI). This disciplinary field comprises of how people implement, design and use interactive computer systems and how these systems affect individuals, organizations and society (Myers et al., 1996). This thesis uses UX as it is defined in International Organization for Standardization (ISO 9241-210, 2010) standard definition as: a human's perceptions and responses that are a result of their use or anticipated use of a system, product or a service. This thesis' main three focus areas are wrapped under the category of UX: AUX which consists of the experiences, perceptions and feelings that the user expects to occur when they are imagining future use of an interactive product or application. Ensuring the users gain positive experiences, UX should be assessed early in the design and development process (Yogasara, Popovic, Kraal, & Chamorro-Koc, 2011).

This thesis structure consists of three focus areas which are presented in Figure 1. The first focus area of this thesis is Gamification. Gamification is usage of video game design elements in non-gaming contexts to improve UX and user engagement (Pelling, 2011). Gamification was chosen as the main design method to assess UX early in the design and development process of the thesis' implementations.

The second focus is augmented reality (AR) a sub-area extended reality (XR) an umbrella term that includes augmented reality (AR), mixed reality (MR), and virtual reality (VR). AR as a term is used on display technologies which superimpose symbolic, alphanumerical, graphical information with haptic and audio stimuli to the user's view of the surrounding environment (Mihelj, Novak, & Beguš, 2014; Aukstakalnis, 2016). The AA functioned as the mediator UI for the AUX study, where the interview participants' experiences, perceptions, and feelings were documented and evaluated.

The third focus area of this thesis was Digital Twin (DT) which is one area of a wide categorization of Industry 4.0. According to (Tao, Zhang, Liu, & Nee, 2019) and (Lu et al., 2020) DTs are digital and virtual representations of their real-world process or system counterparts. The web GDT application is where this study bases its UX design method with gamification and development of the AA used in the AUX study. The web application GDT is also in this thesis iterated and new design layouts are implemented and documented.

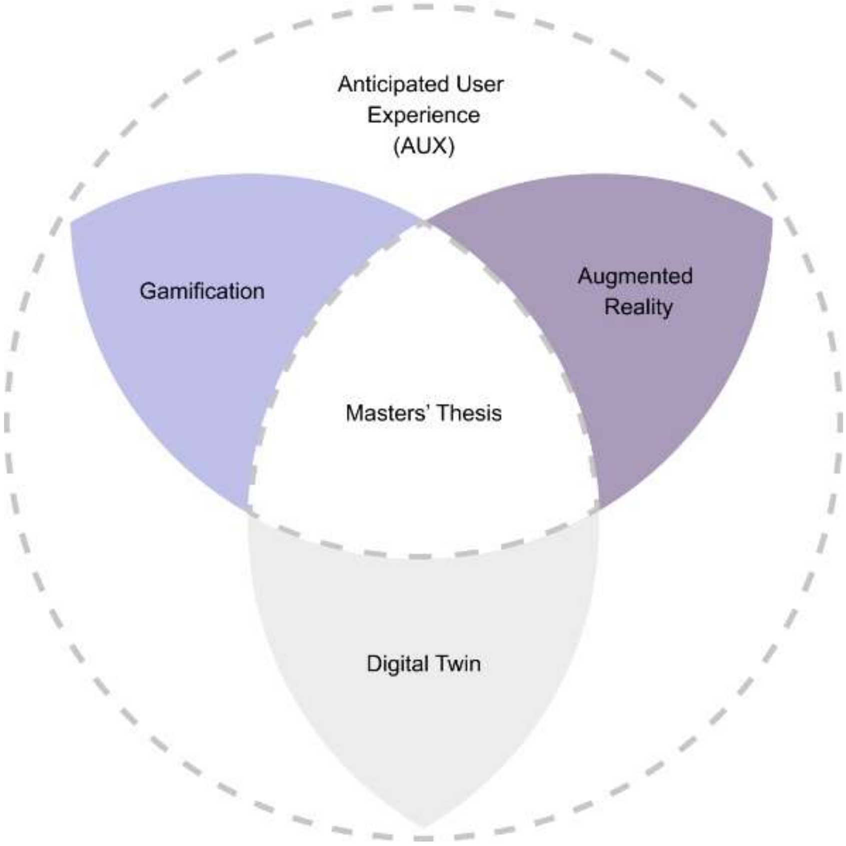

Figure 1. Focus areas of the thesis (Inspired from Pakanen, 2015)spire

This thesis starts by describing and explaining the research questions that related work relevant to understanding the theoretical background and technologies used afterward. This is necessarily important in this thesis as the research subject has a precise focus. After the research terminology and theoretical background are introduced, it is followed by the implementation chapter. In this chapter design and development of the enhanced and gamified web UI and the AA used in the AUX study are documented and their interdependencies are explained. These steps also include quick overviews of the workshops that were conducted with Metso Outotec personnel. The evaluation chapter introduces how the pilot study and interview were conducted, who the participants were and how they were recruited, and how the interview data was gathered and analyzed. The results focus objectively on displaying and documenting the data that was found from the interviews. The resulting data is then interpreted, and the meanings are contextualized in the discussion chapter. The discussion chapter also highlights limitations and future work that the results of the research implicate. Finally, in the conclusions, the research questions declared are restated and a summary of findings and their implications are stated. Figure 2 explains the thesis structure and how workshops, implementations, and thesis writing process proceeded during the thesis project.

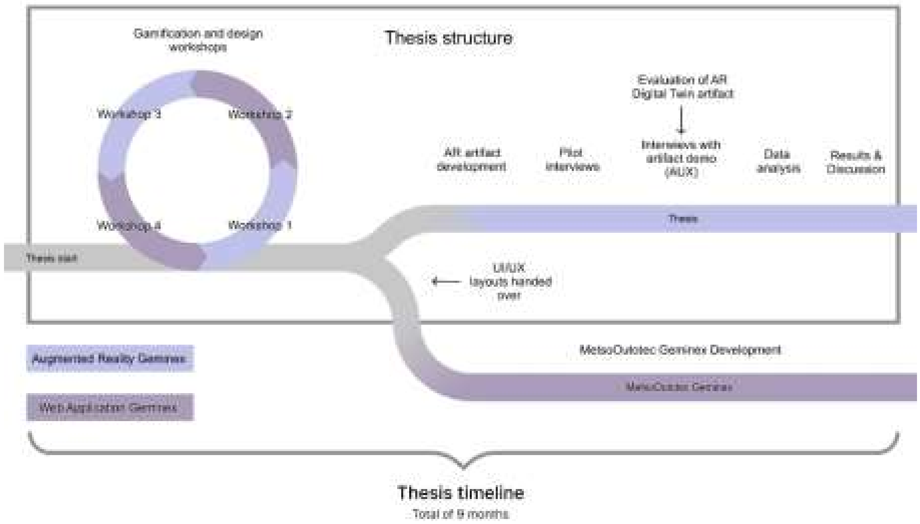

Figure 2. Thesis structure (CC BY 4.0 Juho Toratti).

In this thesis, it is important to note that the thesis work process is comprehensive and broad. In total, the thesis work process spanned along nine months' period which is reflected in this thesis' length and coverage of the subject. In this thesis, there are two implementations instead of one and by removing steps done in the thesis it would have been degrading to the research rigidity and clarity. Both implementations the gamified layouts for web application GDT and the AA as seen in Figure 2 are also closely related to each other which is disclosed in finer detail in the implementation chapter.

2. Related work

In this section I review relevant related work theoretical backgrounds, basic terminology and technologies. They are discussed and explained to understand this thesis are laid out in the following chapters. The explanation is done to help understand and internalize their part in the implementation and evaluation part of this thesis.

2.1 Anticipated user experience

Recently anticipated user experience has brought a new way of studying UXs in the HCI community. As experiences are not only felt by using a product system or a service, but additionally before and after their use (ISO 9241-210, 2010). Anticipations and expectations that happen before the actual use are helpful in the early developmental process and may help with the products development to produce a better experience for the users (Roto, Law, Vermeeren & Hoonhout 2011; Pakanen, 2015).

To define AUX it is important to understand that UX is the humans' perceptions and responses which are a result of their use or anticipated use of a system, product or a service (ISO 9241-210, 2010). Increasingly UX has been used for not its intended purpose but as a glorified term for usability and to an umbrella term for describing any interactions with user and different consumer related services that companies provide (Gegner, Lutz & Runonen, 2012).

AUX as an evaluation method is to identify if early developmental concept or artifact can provide and offer adequate UX to the system, application or service to be developed. This is done by anticipating the future users' experiences (Stone, Jarret, Woodroffe & Minocha). Olsson (2014) noted that when less experienced participants are included in anticipated user experience studies there is an underlying problem as they cannot imagine a possibility for future uses with a technology that conflicts with their current or familiar one. Hence, the participants that are chosen for the AUX study and evaluation methods should be adequately familiar or professionally capable in the respective context and an early developmental design, concept or artifact should be utilized (Kukka et al., 2017).

To understand how expectations and anticipation influence the UX of the users Wright et al. (2008) proposed that they give "shades of meaning" to encounter with the product in question. Arhippainen (2009) claims that the anticipations have an influence in the user's perceptions and views of the actual product's overall quality and capabilities. Of course there are plethora of expectations and anticipations regarding the use of new technologies. If these expectations are met or they are outperformed by the artifact or technology the users perceive increase in post-use satisfaction and decrease if they were dissatisfied (Oliver, 1977). These perceptions from the expectations and anticipations might have a connection with novelty effect that happens when new technology is introduced and tested by users. First impressions of the technology may enhance motivation of the users which may fade over time after prolonged use of said technology (Jeno, Vandvik, Eliassen, & Grytnes, 2019). Similarly the novelty effect of new technology is noted by Olsson (2012) with mobile AR (MAR) context. Olsson stated that the first generation of MAR applications are not yet mature which may cause their novelty value to be overshadowed by their potential capabilities (Olsson, 2012).

Anticipation is defined by Butz (2004) on the conceptual level to be the projections of the user ahead of their mental representations abstracted from their past experiences.

Additionally in AUX the user can anticipate their feelings and experiences before, during and after the use of an interactive product, system or artifact. Roto et al. (2011) also states that users can anticipate UXs before, during and after the first use. These attributes can then be documented during interviews where the users had product, system or artifact (Yogasara et al., 2011). In this thesis I will be using the definition for AUX by Pakanen (2015, p. 22) "experiences, needs, and wishes that result from anticipated interaction with the concept of a product before the actual product". There is a slight change in this thesis how the actual product is interpreted from the definition, as the artifact produced is not kept as the actual product per the definition.

2.2 Extended reality

The accessibility of augmented reality (AR), mixed reality (MR) and virtual reality (VR) is growing in consumer and business sectors and the adoption in applications is ever increasing (Chen, Day, Tang, & John, 2017). Recent technology advancements and on-board sensor integrations in handheld and head mounted devices has also made it easier to adapt the AR technology to commercial media, healthcare (Cidota, Lukosch, Bank, & Ouwehand, 2017; Carlson & Gagnon, 2016), industrial (Ke, Xiang, Zhang, & Zuo, 2019) and educational contexts (Carlson & Gagnon, 2016; Akçayır & Akçayır, 2017). Now that it is possible to develop, and integrate AR, MR and VR applications for added benefit into the workflow of companies and industries, it is becoming common practice amongst them (Evans, Miller, Pena, MacAllister, & Winer, 2017). Recently companies like Google, Microsoft, Meta HTC, SONY, and more have started their own research on the AR, VR and MR HCI technologies which has led to new types of practical uses in industry (Alce, Ternblad, & Wallergård, 2019; Ke et al., 2019). The three variations AR, MR and VR are at the time of writing considered to be unified under one common term extended reality (XR) which will be later referred as such when talking about the three variations (Lavalle, 2019).

VR is defined by LaValle (2019) in his book Virtual Reality to be, "...inducing targeted behavior in an organism by using artificial sensory stimulation, while the organism has little or no awareness of the interference". AR is defined to be a variety 14 of input and output devices that display graphical information overlaying the user's view or integrated into it (Aukstakalnis, 2016). Visualization in AR environments as opposed to VR environments differs. In VR environments the user is surrounded by the generated VE which to a large degree isolates and spatially restricts the user compared to superimposed AR environments (Aukstakalnis, 2016). In AR the user's hands, environment, and objects are superimposed on the existing surrounding environment but are completely virtually visualized and generated with computers in environments generated in VR (Ke et al., 2019). There are two major methods of producing immersive VEs: the first being a stereoscopic head-mounted display (HMD) and the large physical cave automatic virtual environment (CAVE) systems that are projection based computer-generated VEs. VEs are simply just mathematically defined 3D representations of imaginative or real-life referenced objects (Aukstakalnis, 2016).

2.3 Augmented reality

AR has recently become adopted as a technology for consumer-grade products. The advancements in mobile computing, onboard graphics, sensor, and wireless technologies have made easy adoption of AR technology possible. With the easy adoption, the accessibility of modern smartphones has provided a platform and user base for the development of AR-based applications for MAR (Chatzopoulos, Bermejo, Huang, & Hui, 2017; Sarwar & Soomro, 2013; Yovcheva, Buhalis, & Gatzidis, 2012). Consequently, a variety of applications have started relying on the integration of AR features. AR as a term is used on different kinds of display technologies that are capable of superimposing symbolic, alphanumerical, graphical information to the user's field of view (FOV) of the surrounding environment. AR display technologies are usually used in cooperation with technologies providing haptic and audio stimuli UIs to the user (Mihelj et al., 2014; Aukstakalnis, 2016; Milgram & Kishino, 1994; Akçayır & Akçayır, 2017). In this chapter, I will go through the history behind the technology and the different kinds of display technologies along the way.

2.3.1 History

The term AR is modern compared to the first technologies that are later categorized as such. The term AR was first used and defined in the 1990s but the first technology that laid the basis for AR display technology can be traced all the way to the early 1900s when Sir Howard Grubb invented the reflective sight (Janin, Mizell, & Caudell, 1993; Aukstakalnis, 2016).

In the late 1960s, Ivan Sutherland invented the head-mounted three-dimensional display, which would be later named "The Sword of Damocles" (Sutherland, 1968; Boas, 2013). This invention can be kept as the very first head-mounted display, or more specifically a Binocular Omni-Orientation Monitor (BOOM). This type of HMD acted with a counterweight or support for the stereoscopic displays enabling prolonged use (Bolas, 1994). "The Sword" was also capable of tracking head movements which were then reflected in the information displayed, which was considered state of the art and a pinnacle of computer capabilities at the time (Sutherland, 1968).

In the 1970s the first widely used head-up displays, which were the precursors of head-mounted displays, became a common technology used in fighter aircraft and helicopters. The demand came from pilots as they needed a way to perceive important information simultaneously without looking away from the environment. The solution to this was called a heads-up display (HUD) which was mounted in front of the pilots and utilized the same kind of reflective technology as the Grubbs telescope. A plethora of information could be projected and presented to the pilots. These HUDs were later also integrated into the pilot's helmets and the first commonly manufactured HMD precursors were born (Aukstakalnis, 2016). This was also the point when head movement tracking was introduced in a common use case with HUD after the Sword of Damocles (Bolas, 1994).

2.3.2 Concepts

The content of this sub-chapter focuses on different types of AR technologies and their differences are explained here. Also, the interactions and movement are superficially explained to provide a basis for the technological implementation phase later in the research. An overview of gestures, environment mapping, and technologies that are used in the Microsoft HoloLens 2 are also presented.

Head mounted augmented reality

At the time of writing, there are two categories of HMD AR technologies, Optical See-through (OST) and Video See-Trough (VST) (Aukstakalnis, 2016). Both technologies are illustrated in Figure 3. AR display technology can also be found in mobile or handheld devices, in these devices the fundamentals of the technology closely follow the principles of VST AR and will be introduced later and illustrated in Figure 3 and Figure 4.

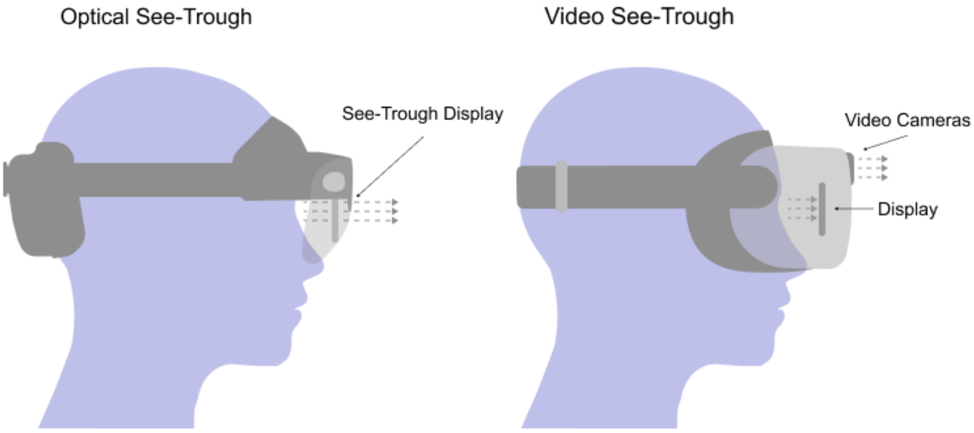

Figure 3. This image represents the two different types of wearable AR HMD technologies and points out their major differences. (CC BY 4.0 Juho Toratti).

Optical see-trough

In OST displays the user views the surrounding environment simultaneously while the HMD projects virtually superimposed symbolic, alphanumerical, or graphical information to the see-trough display (Grubert, Itoh, Moser, & Swan, 2017; Aukstakalnis, 2016). This thesis's technological implementation will be based on Trimble XR-10 with integrated Microsoft HoloLens 2 an HMD with OST-type display technology (Trimble, 2022; Microsoft, 2022).

Video see-trough

Alternatively, the VST displays mediate the surrounding environment through video cameras embedded in the HMD or those installed in a remote location (telepresence) while simultaneously displaying symbolic, alphanumerical, or graphical information on top of the displayed video feed (Grubert et al., 2017; Aukstakalnis, 2016). Example devices utilizing this type of MR technology are Quest Pro from Meta Platforms Inc. and XR-3 from Varjo (Varjo, 2022; Meta Platforms Inc., 2022).

Handheld augmented reality

Alongside the AR HMD technologies, a more accessible form of AR display technology can be found in your everyday smartphone or tablet computer. As these devices provide an accessible platform for consumer and commercial AR applications, and because of their capable and suitable sensors, software companies have started to integrate AR features and applications into them. Comparatively to expensive AR HMDs, tool exclusive for AR solutions, handheld augmented reality (HAR) or mobile augmented reality (MAR) is currently the most affordable and accessible form of AR technology due to the widespread use of capable and suitable handheld devices (Mihelj et al., 2014; Polvi et al., 2016). This technology is used widely in advertisements, tourism, museum, location-based games, pervasive games, and navigation applications. These kinds of applications rely heavily on location data and superimpose information based on that data (Alavesa, 2018; Milgram & Kishino, 1994; Akçayır & Akçayır, 2017). An example of HAR can be seen as illustrated in Figure 4.

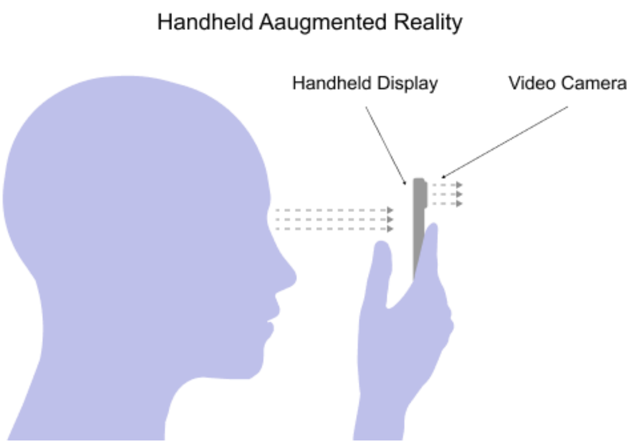

Figure 4. Handheld AR uses a handheld display to mediate the surrounding environment through a video camera on the device's screen (CC BY 4.0 Juho Toratti).

HAR works similarly to VST AR, but the major difference is that the view only partially consisted of the video feed and superimposed information depending on the size of the handheld device (Aukstakalnis, 2016). Handheld devices must be pointed manually by hand to see the superimposed data. For example, in Pokémon GO, a map-based augmented reality game this particular entity of Pokémon (Squirtle) shown in Figure 5, is only superimposed to view in this specific location (Paavilainen et al., 2017). Handheld devices, particularly smartphones are bringing LIDAR to the AR field. LIDAR provides high spatial resolution for environmental real-time mapping, enables extensive content production and more accurate placement of digital superimposed content in the physical environment (Jaboyedoff et al., 2012; Zhang & Singh, 2014). Example of a mobile device using LIDAR at the time of writing; Apple iPhone 14 Pro (Apple, 2022).

Figure 5. This image displays how Pokémon GO, a mixed reality mobile game uses handheld AR technology to display the environment superimposed with UI elements and an interactable Pokémon on the same screen (CC BY 4.0 Juho Toratti).

2.3.3 Interactions and movement

Compared to AR, VR is fully immersive, and the VE space can be infinite even if the user is spaced in a finite space. The movement can be distinguished into a physical movement for tasks that happen in the user's vicinity in limited spaces or through generated user interfaces and interactions when inquired to traverse vast distances. The navigation in vast spaces is usually implemented in a way that keeps physical movement at a minimum to improve safety and counter possible nausea caused by the sensory mismatch. This sensory mismatch is caused when observed and expected sensory perception differ (Rebenitsch & Owen, 2016). For example, people using immersive VEs tend to estimate distances incorrectly, usually by underestimating the distances and causing sensory mismatch when they move. An experiment by Jones et al. (2008) concluded that underestimation of distance while moving was not perceived in AR VEs as opposed to VR VEs. Though an experiment done by Swan et al. (2007) alternatively had an opposite conclusion about depth underestimation on AR VEs, Jones et al. (2011) later clarified the opposite conclusions to be because of movement and staying stationary. From these experiments, it was concluded that in AR VEs, distance estimations greatly improve when movement is linked to the real environment (RE) (Jones et al., 2011).

A rigid body or user moving in VE and space has six degrees of freedom (DOF) (Lavalle, 2019). The user's movement or the first three DOF of 3D rigid body translation in VR can be usually assisted with teleportation to combat nausea. Slight movement without teleportation is possible; however, this can be limited by the HMDs cable and the finite space in use. A battery-powered HMD is better for movement, as they are not limited by the cable length, but tend to sacrifice computing power and battery life for greater freedom of movement. The latter three DOF differs usually in the AR environments where translation and rotation are perceived simultaneously in the real environment

(Aukstakalnis, 2016). On par with movement, the tracking of spatial orientation and rotation is also important, the HMD must be able to accurately measure the head, position, and rotation as even slight tracking inaccuracy or latency is perceived as a sensory mismatch and may cause nausea for the user. For movement, orientation, and rotation AR and VR HMDs also use the Cartesian coordinate system as spatial coordination as all 3D applications. This coordinate system consists of three perpendicular axes X, Y, and Z, which relate to physical translations visualized in Figure 6 and rotations perpendicular to these axes as illustrated in Figure 7 (Aukstakalnis, 2016; Microsoft, 2022).

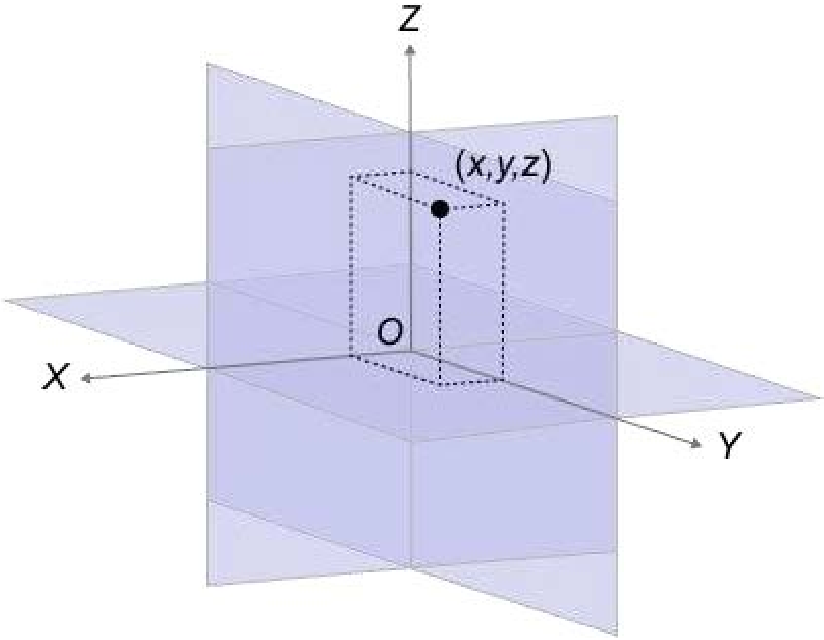

Figure 6. Cartesian 3D coordinate system. Translations in Y-axis (forward and backward), X-axis (left and right), and Z-axis (upwards and downwards) form the first 3DOF of the total 6DOF (Adapted from, Aukstakalnis, 2016).

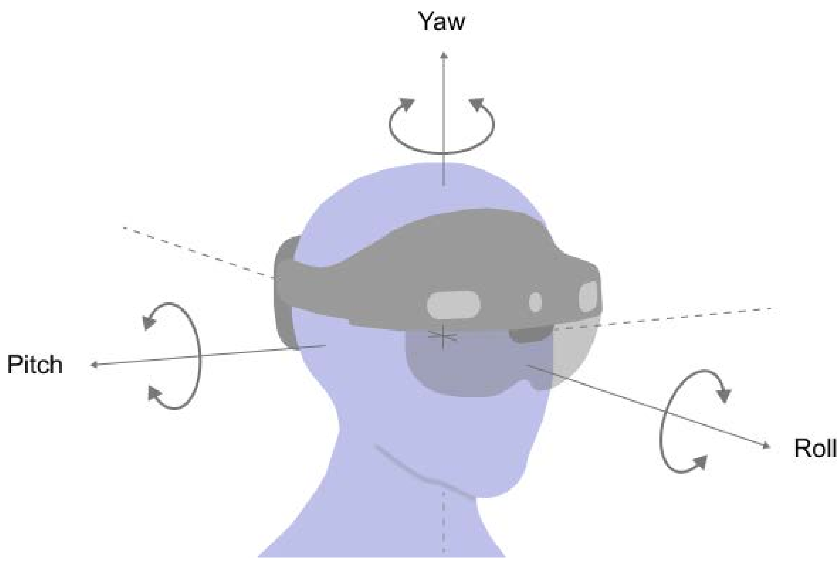

Figure 7. Pitch, yaw, and roll which represent the different rotations in 3D space and together form the latter 3DOF. These rotations with translations form together 6DOF (adapted from, Aukstakalnis, 2016. CC BY 4.0 Juho Toratti).

Spatial mapping

While wearing HoloLens 2 the HMD simultaneously scans the surroundings and creates a spatial map of the surrounding environment. When the environment changes 20 the spatial map constructed is updated by HoloLens 2 in real-time. This mapping is also possible with MAR and HAR and the spatial maps can be converted int After the initial spatial map of the environment is done the user can see the mapped spatial map as a wireframe if this feature is enabled. A high spatial resolution map of the environment enables accurate placement of digital content in the spatially mapped physical environment. Positional data can also be gathered while using MR HMDs, which means that the devices can provide spatial maps, and produce LIDAR-based imported 3D models of the environment (Microsoft, 2022; Huo et al., 2018). When spatial mapping and continuous tracking of the user are combined this is called simultaneous localizing and mapping (SLAM) (Stachniss, Leonard, & Thrun, 2016).

Spatial sound

MR applications usually have a greater need for spatial audio than 2D applications because of the absence of a haptic or tactile interface. Spatial sound While VR users have the option to use haptic controllers and exoskeletons with tactile interfaces in their interactions with the VE, MR users cannot utilize these as they are interacting with both virtual and physical objects (Microsoft, 2022; Lopes, You, Ion, & Baudisch, 2018). This makes it hard for MR users to utilize haptic and tactile interfaces as their hands should be kept unencumbered and this greatly rises the importance of audio feedback cues provided by spatial audio. Spatial audio feedback requires for minimum the heads orientation which can be determined with pitch, yaw, and roll rotations (Fig. 4). This is because the human ability to determine the absolute position of the sound’s origin in 3D, is more accurate in horizontal and vertical positioning rather than with distance (Begault, 1999; Sodnik, Tomazic, Grasset, Duenser, & Billinghurst, 2006; Aukstakalnis, 2016).

Hand tracking

Hand tracking is implemented in MR headsets with multiple cameras. In hand tracking the index and palm joints are more accurately tracked than other joints, because of their importance in different gestures. In HoloLens 2, AHAT, A high-frequency 45 frames per second (FPS) short-throw method is used for near interaction hand tracking. Hand joint tracking can be seen in Figure 8 and a spatial geometric map of hands in Figure 9. Far interaction is implemented with long-throw low-frequency 1-5 FPS, spatial mapping (Microsoft, 2022).

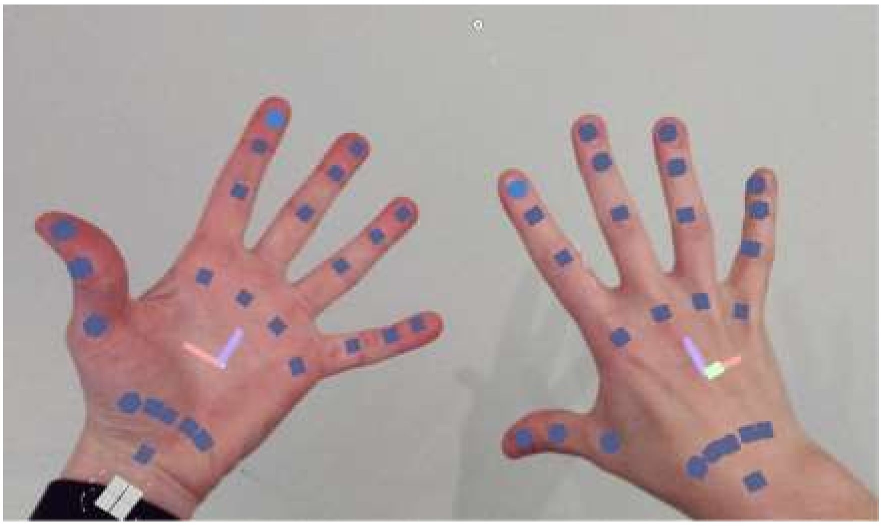

Figure 8. Hand joints generated with HoloLens 2 AHAT short-throw method (CC BY 4.0 Juho Toratti).

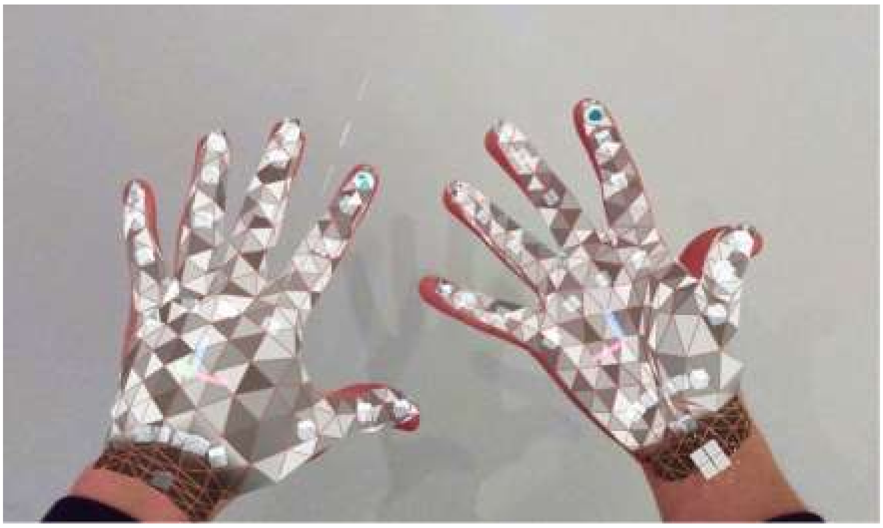

Figure 9. Hand spatial map generated with HoloLens 2 AHAT short-throw method (CC BY 4.0 Juho Toratti).

Gaze tracking is a newcomer in the HoloLens 2 compared to HoloLens. Gaze tracking avoids storing the biometric information of the users. By gaze the user can determine different interactions or gain additional data on interactions. Attention or focus tracking can be used as a powerful tool in user research, training and performance monitoring, remote eye-gaze visualization design evaluations, marketing, and even in consumer research (Microsoft, 2022). Gaze tracking technology can also be found in Varjo XR-3 and Meta Quest Pro (Varjo, 2022; Meta Platforms Inc., 2022).

Composite gestures

Gestures are one of the primary ways to use the UIs in AR applications. Gestures work mainly by tracking hand movements with cameras and providing articulated hand tracking. Basic gestures range from point and commit which can vary from manipulating objects by pinching them to pushing a virtual button with your index finger (Microsoft, 2022).

Voice input

Voice inputs or commands are also a way of interaction in UIs in AR applications. Voice commands usually support gestures and can be useful shortcuts in complex interface menus with nested menu functionalities. The voice input in HoloLens 2 is powered by the same engine used in other Universal Windows Applications (Microsoft, 2022).

2.3.4 Benefits

Compared to VR where the user is fully immersed in the VE AR is likely more conventional and safer in addressing the issues that VR users have with a lack of attention to their surroundings. While partially immersed in the AR environment the user is still aware of their surroundings and can clearly observe the environment. Also with AR OST, these are also the cases why AR display technologies are more widely used and adopted into industry settings than VR. While VR technology can be used for educational and training purposes AR shines on the practical uses in the actual work done on the shop floor and outside of the control room (Delgado, Oyedele, Demian, & Beach, 2020). One other case at least for HMD technology is that the user can free their hands from traditional input and output -devices like keyboards, mouses, or controllers as their display is mounted into their head. While the hands are freed, the user has the freedom to interact with their surroundings. There are also security concerns with the HMD options because they still partially immerse the user which may draw their attention more than a smartphone or a handheld computer in the workplace (Kim, Nussbaum, & Gabbard, 2016; Hou, Wu, Zhang, Tan, & Wang, 2020).

2.4 Gamification

Gamification is already an established term as it was first coined by Nick Pelling in 2002 but did not gain popularity at the time (Pelling, 2011). The first description of the term came later by Deterding et al. (2011a) they described it as “the use of game design elements in non-game contexts.” Deterding et al. (2011b) later talks about Gamification as an umbrella term in which video game elements are used in non-gaming contexts to improve UX and user engagement. In recent years commercial software has seen massive development with UI elements and UX which take inspiration from video games. More frequently commercial software that is inherently not designed with entertainment in mind have been integrated with game design elements (Deterding, Khaled, Nacke, & Dixon, 2011; Pelling, 2011) Most common usage for gamification elements is in learning and educational software (Hamari, Koivisto, & Sarsa, 2014). This contains language learning software like Duolingo (Huynh, Zuo, & Iida, 2016).

Simultaneously with gamification Serious Games (SG) has gained popularity in the educational and training context. Described by a plethora of academics in the industry with slightly different or special definitions that make the software a serious game (Laamarti, Eid, & El Saddik, 2014; Susi, Johannesson, & Backlund, 2007). In industry settings, academics believe that an SG must include a game design element combined with a practical dimension (Michaud & Alvarez, 2008). It can be related now to all fields varying from defense, education, training, health, policy, and ecology, so currently SG is ubiquitous to the HCI field (Alvarez, Djaouti, et al., 2011; Mittal, Scholten, & Kapelan, 2022). The main difference between SG and gamified software is that SG is not inherently meant to be entertaining to the user.

As gamification is becoming more accepted and used in the context of education and learning, it has also caused an interest in more sophisticated and serious kept contexts. Plethora of companies have started to add gamification elements to their existing software and are adopting them as a baseline for their software products. “Gamification achieves benefits through employee and general consumers’ engagement and promoting behavior change” (Paravizo, Chaim, Braatz, Muschard, & Rozenfeld, 2018).

2.4.1 Motivation

To understand how new technological implementations and advancements in the industry happen and how current mindsets or behaviors can be changed, it must understood what motivates people. Motivation can be categorized as extrinsic motivation, intrinsic motivation and amotivation (Deci, Nezlek, & Sheinman, 1981; Gopalan, Bakar, Zulkifli, Alwi, & Mat, 2017). The extrinsic motivation of these three in an industrial context is highly dictated when safety is a concern. If something acts as a preventive measure or positively increases the safety on-site it is implemented nevertheless if it has an intrinsic motivational base. But this intrinsic motivation can be assessed by highlighting their contribution to the overall safety and how supervisors and colleagues react to said safety adoption (Andriessen, 1978). Research done by (Mitchell, Schuster, & Jin, 2020) with sample size (n = 291) across different industrial fields, supported the importance of behavioral impacts of intrinsic motivation in the workplace that gamification had. The study proposed that designing enjoyable and 23 interesting solutions was the key to sustainable and efficient applications. Also, another study conducted by (Sailer, Hense, Mayr, & Mandl, 2017) with sample size (n = 419) suggested that gamified design elements successfully affected competence needs satisfaction and contributed to perceived task meaningfulness.

2.5 Digital twin

Industry 4.0 refers to a wide adaptability of concepts of smart manufacturing which is also a synonym for the term. Industry 4.0 focuses on machine learning, ubiquitous computing, cyber-physical systems, interconnectivity, and real-time data usage in the industrial context. Rapid advancements and developments in digital technologies and their continuous integration into the industry have caused a worldwide change in the manufacturing industry. One of these advanced technologies is called DT (Lasi, Fettke, Kemper, Feld, & Hoffmann, 2014; Tao et al., 2018).

The concept of DT was first coined by Grieves in 2003 (Grieves, 2014). During this period, the concept definition consisted of three parts: physical product, virtual product, and the connection between those two. Later in 2012, the concept started to gain momentum as the National Aeronautics and Space Administration revisited the concept and proposed an explanation from the perspective of aircraft and spacecraft vehicles.

> *"A digital twin is a integrated multiphysics, multiscale, probabilistic simulation of an as-built vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its corresponding flying twin" (Glaessgen, & Stargel, 2012, pp. 7)*

This explanation can be adapted to the whole of Industry 4.0 by changing the aircraft or spacecraft context into from the different fields in manufacturing, like in this research context to a raw material manufacturing and enrichment industry (Glaessgen & Stargel, 2012). Correspondingly Tao and Zhang (2018) (Tao et al., 2019) describe the DT as a method for the convergence of physical and virtual spaces. Later Tao, Cheng, Qi, Zhang, Zhang, and Sui (2019) (Tao et al., 2018) summarized and specified DT into three descriptive categories. Real-time reflection: Two spaces exist, virtual and physical where the virtual space reflects real-time data from its physical counterpart. Interaction and convergence: Historical and real-time converged data in a fully integrated DT system can be studied and statistically compared to make data into information that is more comprehensible and useful. Continuous interactions with the physical and virtual space do not isolate the systems. Self-evolution: Collected and updated real-time data can be used to improve and evolve both the physical and virtual space functionalities in parallel.

Using AR's VE and RE as a contrast it is easier to explain similarities between them and the DT physical and virtual communication. I propose that the RE perceived is the physical space or product of DT and the superimposed VE is the virtual counterpart. This furthers a proposal that their interrelationships or connections are both real-time reflections of their physical and virtual counterparts. It could be argued that if an AR application uses the data from the RE and continuously integrates it as a part of the VE, these applications with superimposed environments can be categorized to 24 work like DT. This relatedness in terms and functionalities provides possible solutions to a problem that traditional UI's have on where DT is implemented. This relation can be better understood by combining the proposal with the Virtuality Continuum by (Milgram & Kishino, 1994) illustrated in Figure 10. AR has become an intuitive way to represent real data from the environment while simultaneously overlaying or superimposing data to the user. AR can bring the virtual and physical counterparts together by continuously integrating the site or systems data into the AR DT applications. On par with the ability to show data e.g., KPIs, numerical data, and warnings straight in the physical machines on site, this makes it also possible for telepresence, the user can feel that they are on the site remotely even if they are far away. 1:1 scaled constructs of the actual environment make it easier to understand the whole process and any interdependencies of system components on-site (Tao et al., 2018; Lasi et al., 2014; Delgado et al., 2020).

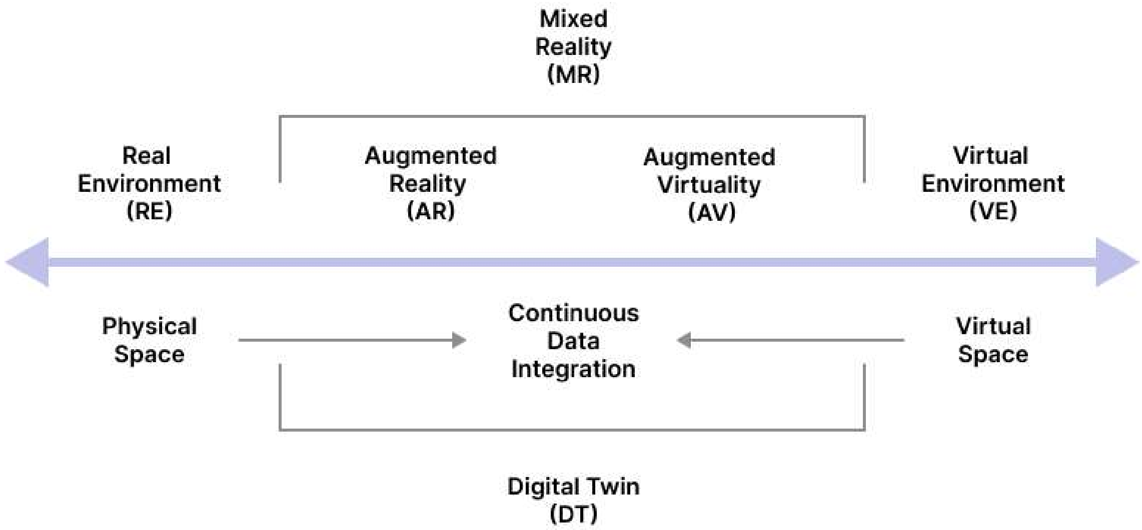

Figure 10. Virtuality Continuum and Digital Twin physical and virtual space convergence relation (adapted and enhanced image from Milgram & Kishino, 1994. CC BY 4.0 Juho Toratti).

2.5.1 Key performance indicators

Different companies are using KPIs incorrectly in manufacturing operations management and are not really monitoring their true KPIs. This has been mainly due to the incorrect explorations on what KPI is. Parmenter (2015) (Parmenter, 2015) lists four different performance measures that are usually used. Key result indicators display perspective or critical success factors, result indicators display the things you have done, performance indicators tell you what to do based on the data and KPIs display data on what to do to increase performance drastically. Incorrectly first three of these performance measures are used interchangeably with the actual meaning of KPI. According to ISO standard number 22400, KPIs are strategic and quantifiable measures that reflect a company's critical success in factories in their respective industry (ISO 22400, 2014).

The KPIs are also present in the accurate modeling of DT data. As the DT one of the main functionalities is to display historical and real-time data and if this data is not given meaning through a distinguished KPI it really does not make sense to just display raw data through the DT. Therefore, different data gathered from the physical DT is categorized and measured through appropriate KPI values. KPI values can represent planned times and actual times of the same processes. KPIs help in increasing the performance of the system by enabling a comparison of planned and achieved results from which simulated or predictive data can be turned into information and adopted into enhancing performance with machine learning or with the human factor. DTs can in turn use these planned and actual times to calculate and compare KPI values performance and act upon them. Rather than making the decisions based on the management level in the site, DT brings into the table the possibility to offer the right decision-making with criteria methods learned by the DT from derived data (Chan & Chan, 2004; Parmenter, 2015; Papacharalampopoulos, Giannoulis, Stavropoulos, & Mourtzis, 2020). Handful of examples of KPIs used in manufacturing (ISO 22400, 2014; Papacharalampopoulos et al., 2020). Actual production time (APT): processing time, setup time and handling Time combined. Planned production time (PPT): Planned processing Time, setup Time, and handling time combined. Raw materials inventory (RMI): Finished goods inventory (FGI): These types of KPIs can be compared and conclusions could be drawn when these are attached to the DT. The possibility to determine actual problems or bottlenecks in the system can be easier the more KPI values and accurate data are gathered from the actual soft and hard sensors of the physical system.

3. Implementation

The thesis study has two use environments for the *Geminex* digital twin developed by Metso Outotec, a traditional a web-application and an AA. These applications rely on the data flow that is provided by the actual system through Microsoft Azure cloud services. Both applications are considered DTs which gather key performance indicators (KPI) from an industrial gold enrichment plant. In this research the GDT applications KPIs come from a gold enrichment and manufacturing plant located in Bulgaria. The GDTs idea is to make educated guesses or predictions based on the real-time KPIs flow mediated from hard and soft sensors in the enrichment plants manufacturing process. The KPI coming from the site is then processed, contextualized and categorized by the GDT and presented to the user graphically trough UI. These real-time KPIs from the site becomes information which the user uses to run KPI driven predictions with GDT on how the industrial process will progress. The results and flow of these of the simulations can be read while the simulation is running and afterwards. The simulation scenarios and KPI may be then altered or saved for later use in the GDT UI.

The use cases and experiences in the applications differ, as the traditional web application of GDT is intended to be used from a computer or a laptop which requires the use of a computer screen, mouse and keyboard, to use the current iteration of the application effectively. For these reasons mentioned the use of the web application is mainly stationary in nature and does not allow room for user mobility. When considered the industrial setting and manufacturing environment onsite, carrying a laptop with different I/O devices is hazardous and hard to use on-site due to lack of use space and hand freedom. While moving on-site it is mandatory to have one free hand as it is used grab the safety railings and support the movement. So, when using the GDT with a laptop the user would need to pack it during movement on-site. It was discussed that one of the problems of current iteration of GDT is that it is highly immobile platform to use in the manufacturing industry, which could be solved by HMD AR technology.

3.1 Workshop process in project

During this thesis project in Spring 2022 and Fall 2022, excluding summer holiday season, there were a continuous arrangement of workshops with the Metso Outotec personnel. The personnel ranged from metallurgists, experts in mining processes and marketing and people with design expertise. Educational levels in the workshops also ranged from people with candidate to master’s level and all the way to PhD’s. The majority of workshop were face-to-face in Espoo office. These workshops and their agenda are superficially explained and illustrated in the upcoming chapters to give an approachable overview of the process.

The workshops were done to re-design some elements of the existing product and by proposing gamified elements for the application. New design layouts and ideas for the UI and UX were continuously proposed and iterated in the workshops. The complete layouts were designed in Figma a design tool and platform for UI design. These proposed layouts and designs were also iterated continuously in workshops with the Metso Outotec personnel. Some designs were scrapped and while others were focused due to tight project iteration schedules. Miro a visual collaboration platform for teams was used to store the material, notes and documentation produced in the workshops.

The first meeting and the first three workshops were held in the Spring of 2022. The last workshop was held late in the Fall of 2022 after the UI and UX layouts had been implemented to the GDT, these changes were introduced to key peers after the research projects interviews had been held.

The figures used to present each step of the workshop process are included as thumbnails. As the results or from these workshops are not the focus and implementation of this thesis. Rather the outlaid figures from the workshop session are presented in thumbnail format to help the reader comprehend the research process and implementation phases that went through in the workshops.

As a result of these expert workshops that were held during the research project, the GDT got an UX overhaul in relation to new features and solutions for simulation processes and monitoring. Advanced results for how gamification can be utilized on industry context and how it enabled a different perspective to design was perceived. Evaluations and conclusions from these expert workshop processes and their results will be discussed and researched further on the paper to be submitted (Alavesa, P., et al. 2022).

3.1.1 Project launch meeting

The first project meeting was hosted in Metso Outotec facilities in *28.3.2022*. This meeting consisted of explaining the basic use cases of GDT, how it looks and how it works currently and what kind of new features are under work. Also a tentative timeline for this project was set and this meeting functioned as the first face-to-face meeting between the research project peers. After getting familiar and up to date with the current GDT UI and upcoming features, the meeting agenda continued with brainstorming workshop where current design and development ideas Metso Outotec had been walked through, and future designs and features were proposed based on them.

3.1.2 First workshop

Before the first workshop hosted by Metso Outotec in Espoo, a pre-meeting in *8.4.2022* regarding the concept was held. In this meeting the agenda for the upcoming meeting was discussed. Use cases, personas, main problems were outlined and what how the data would be gathered that is generated in the upcoming workshop. In the premeeting concept sketching and storyboarding was decided to be used. Participants were mediated that the workshops preferred face-to-face attendance, but agreement was made that the meetings had a hybrid session option for accessibility reasons. Figure 11 shows a quick overview of the Miro board that was used in the workshop session.

Figure 11. Screen capture of a Miro Board from the first workshop. (Metso Outotec, 2022, with permission)

In the first workshop that was held in *13.4.2022* there were 10 participants and it lasted for 2 hours and 30 minutes. The main purpose of this first workshop was to assess mining process control and overall mining process and draw thoughts and ideas based on these contexts. The participants were divided into half, into prediction and monitoring team. These teams then produced storyboarding sketches from their respective contexts. This workshops results proposed that more focus should be done with the WEB application navigation and to fluency of running simulations. In AR HMD context there were conceptualizations that regarded interactive mapping of site, accessibility to KPI and performance data with QR codes or by just viewing and data availability to different mediums. These findings and issues were outlined, prioritized and organized in an online brainstorming meeting with the same participants held in *20.4.2022* after the actual workshop.

3.1.3 Second workshop

The invitations were sent for participants of the first meeting. The second workshop took place in *29.4.2022* and lasted for two hours. A pre-task was set up for this workshop where participants outlined ideas from and for AR, games and applications and their UI designs they endorsed. In the second workshop gamification as a design method was introduced. An overview on gamification in serious context were explained and this provided information and knowledge for the participants on what implications this provided particularly in the industrial mining context. The identified problems from the first workshop were assessed and UI wireframes were produced as layout solutions to solve the navigational problem and fluency to simulations for the GDT UI. These problems can be superficially overviewed from the Figure 12. These ideas and layouts were the precursors and building blocks for both the project UI/UX layout deliverables and the AA used in the interviews.

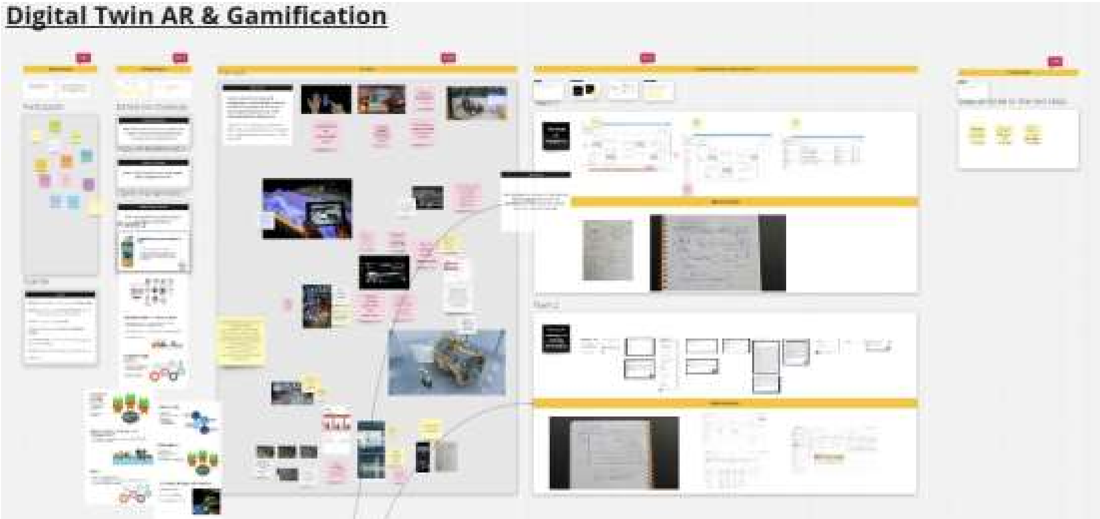

Figure 12. Screen capture of a Miro Board from the second workshop. (Metso Outotec, 2022, with permission)

3.1.4 Third workshop

The third workshop was held in *6.5.2022*, its length was two hours and it continued straight from where the second workshops agenda. Here the design and UI sketches for navigation and simulation fluency were revised and new sketches were built. New ideas were incorporated into the ideas that were proposed in the second workshop, and they were added in the new sketches that were made in this workshop. An overview of the session can be seen in Figure 13. For follow-up tasks I was given the task to design high level layouts prototypes based of the UI sketches. These layouts were designed using Figma and they utilized the Metso Outotec Design System aka *Modes*. *Modes* is a collection of assets, components, guidelines and principles on how Metso Outotec digital products and services should be developed. The assets or in this context Figma component libraries on par with gamification design method were used to design the prototype layouts that can be overviewed superficially from Figure 14. These layouts were then presented to the GDT development team a meeting where the prototype was iterated from the received feedback.

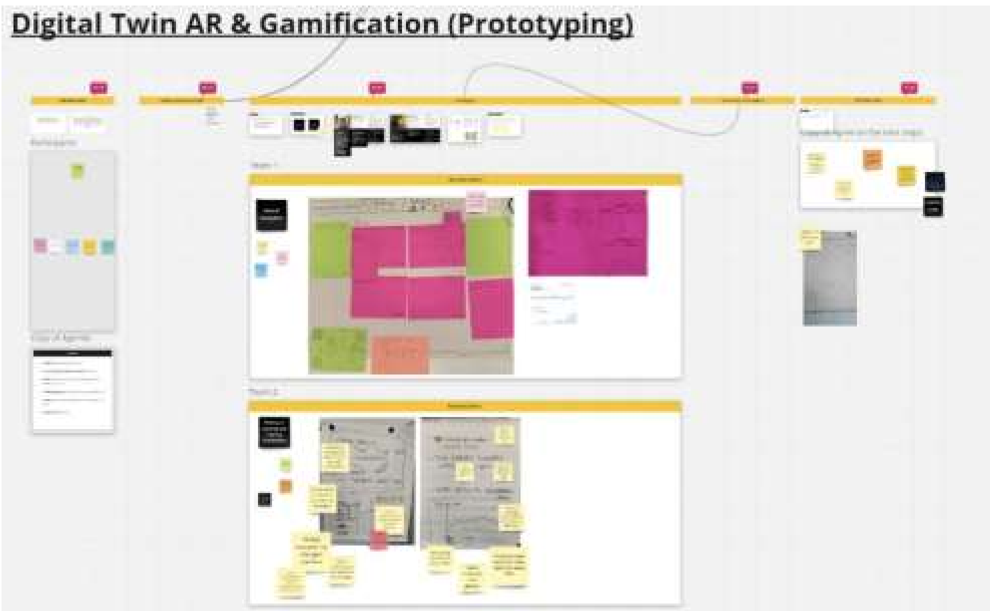

Figure 13. Screen capture of a Miro Board from the third workshop. (Metso Outotec, 2022, with permission)

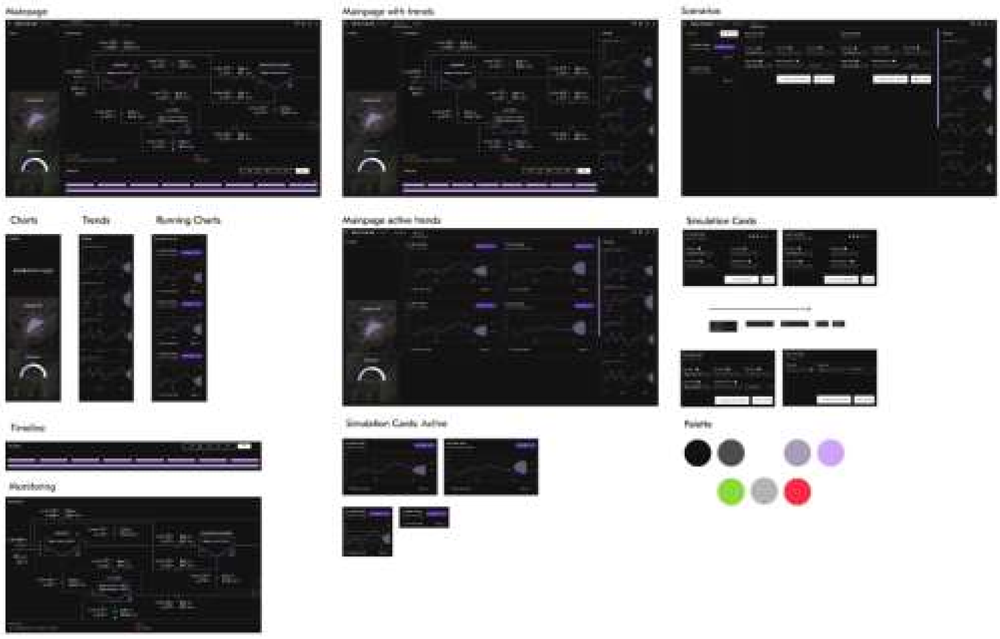

Figure 14. First UI/UX layout iterations that were presented in the fourth workshop (Juho Toratti, 2022).

3.1.5 Fourth workshop

The fourth workshop was held in *11.10.2022* this workshops idea focused on compiling and gathering the elements and ideas the team had found in the previous workshops. This workshop also functioned as a medium to propose the ideas and findings to the new UI/UX designer of GDT. Similarly, as in the second workshop for participants the gamification design method was introduced in industrial context and its implications were introduced to the new designer. Also, new ideas and design proposals were introduced that I had identified during the interviews in the Section 4.3. The new and old gamified ideas were then categorized using an illustrative image with gamification categories. An overview of the sessions results can be viewed from Figure 15.

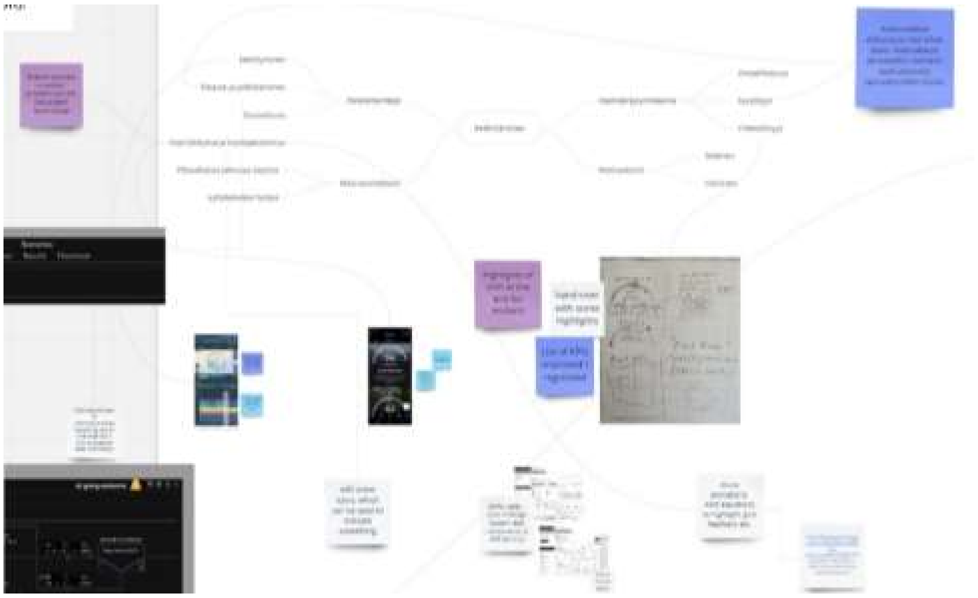

Figure 15. Screen capture of a Miro Board from the fourth workshop (Metso Outotec, 2022, with permission).

3.2 Geminex web application design

After the prototype iteration was ready a finalized UI layouts were produced. Here *Modes* and gamification design method was used to produce the final layout handover. The design layouts were given to the GDT development team and the research and authors focus turned to the AA development. These final layouts were actualized and developed into the GDT UI. The final layouts produced can be seen as a thumbnail overview in Figure 17. First major change that can be noticed is that the first prototype layout uses the *Modes* dark theme, and the finalized layouts used the basic white theme. Both layouts used the same color palette as main color options, which can be superficially overviewed in Figure 18. The color values are derived from *Modes* by Metso Outotec (Metso Outotec, 2022).

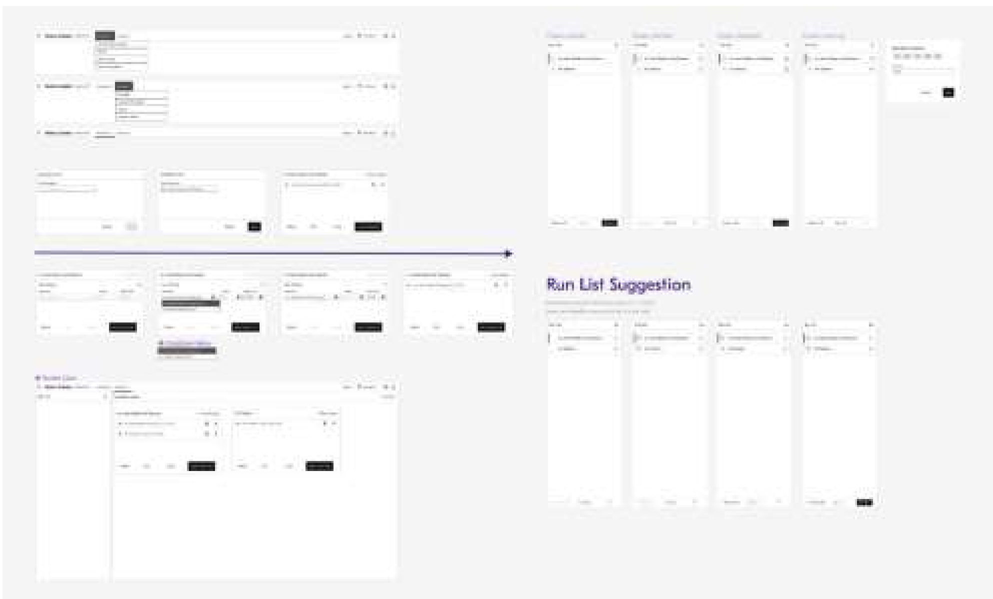

Figure 16. Screen capture of the finalized UI layouts that were handed over to Metso Outotec (Juho Toratti, 2022).

Figure 17. Main color palette used in all the UI designs. These colors are also used later in the AA (Juho Toratti, 2022).

3.3 Augmented reality artifact development

The AA implementation will be crucial to integrate and mimic with the traditional UI of the GDT. With the integration of UX/UI aspects, usability it is important to sustain the feel and look of the web UI version. In addition, both the GDTs web UI and Aas AR UI should be distinguishable as Metso Outotec products. When implementing the AA, it is important to first focus on a proof-of-concept type of application that can be then evaluated and used in the actual AUX study. The AA will be then presented in the visit to the site in Bulgaria and AR related interviews will be held. Aspects of the AA will inherit design principles from the corresponding designs that were used in the UI layouts designed by me for the GDT application. These design principles included the colors used in Figure 17. A gauge type design feels, and design identity of the dark theme designed by me based on the themes in GDT. The mill used as the basis for the AA is an accurate model of a real SAG Mill machine based on a mill produced by Metso Outotec that was 3D modelled with Blender and exported to Unity.

3.3.1 Presentation artifact

In the first iteration of the AA which was presented for the first time in Microsoft Teams Meeting for the peers in Metso Outotec. The topography 3D model of the site was cleaned up. In the cleanup, tens of thousands of vertices were removed and simplified in Blender to increase performance. Also, the 3D topography map model was transformed into a circular shape. The starting point of the 3D model is presented in Figure 18 on the left side and the finished model in right. The top-down map UI type of approach was chosen as it provided an interface on where the user could navigate through different accurate locations on-site. This would have also made it possible to look at the big picture of the processes. From the map UI view the user could have chosen the facility containing the machines in the GDT system and open a scene where the machines were laid out in view. This view would have included all the machines present and their respective data displayed on them like in the actual AA in Figure 17.

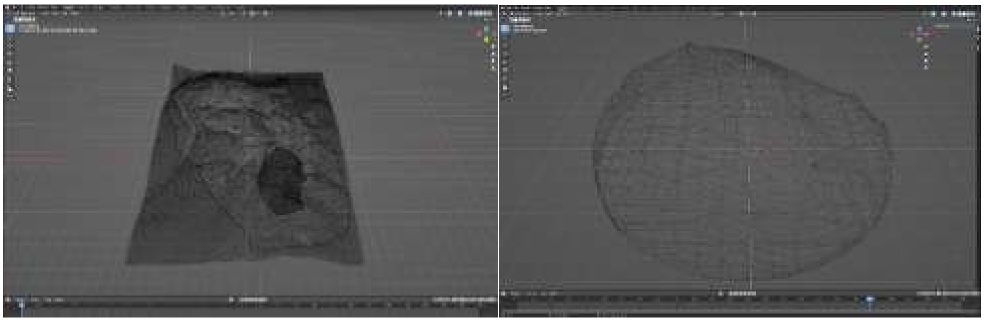

Figure 18. Screen captures from Blender showing the original 3D topography model map in wire frame detail on left and the cleaned one on the right (Juho Toratti, 2022).

The presentation iteration of AA showed how the environment could be presented in AR applications and contained some interface functionalities. This presentations idea was to demo the peers in Metso Outotec on what is possible with the AR technology and how the Trimble XR-10 with HoloLens 2 medium works. This presentation artifact of the demo artifact in Unity can be seen in Figure 19.

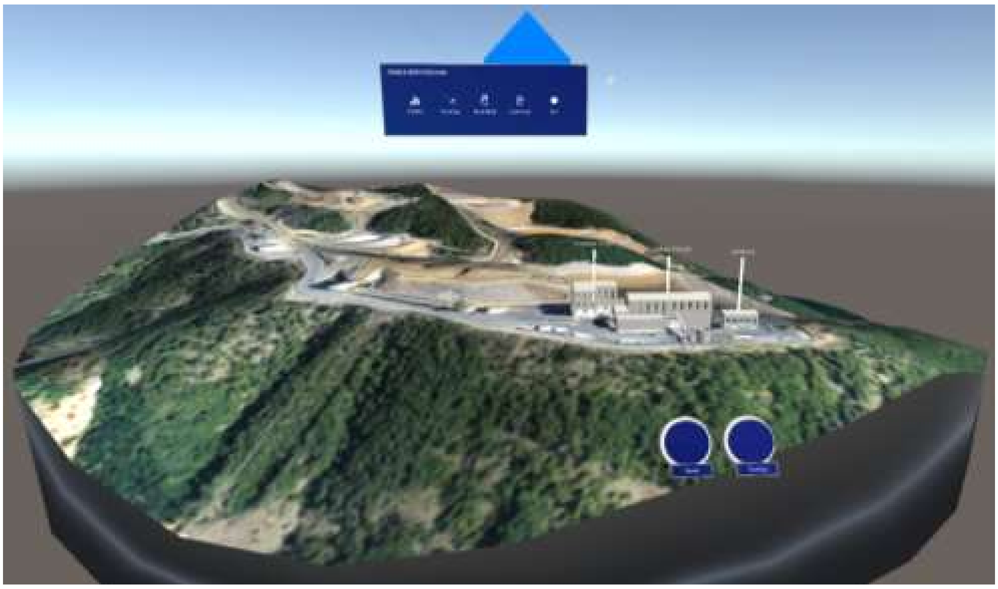

Figure 19. Screen capture from Unity presenting the artifact application that was used in the presentation (Juho Toratti, 2022).

3.3.2 Artifact application implementation

The actual AA implementation process did not continue straight from the first presented iteration of the application. At this point of the thesis and implementation 34 process the construction of a whole site wide AR application was impossible. The amount of data and resources needed to map a site that could be used was enormous and to produce 3D models of them would have needed a team itself. This is also the reason the SAG Mill used in the AA was modelled and textured for me, to save time from the actual implementation, research, design and coding needed in the AA. The SAG mill presented in Blender can be found below in Figure 20 The amount of thesis project time that was used in the design and preparation process on the GDT also took a significant time. There was a need for the GDT project to have an actual UI/UX designs implemented that would be developed by Metso Outotec before the AR application implementation could start. Working as an actual UI/UX designer to implement these layouts took time from the actual AA, but it also gave me insight on how the GDT works and what kinds of solutions could be used later in the AR applications implementation process.

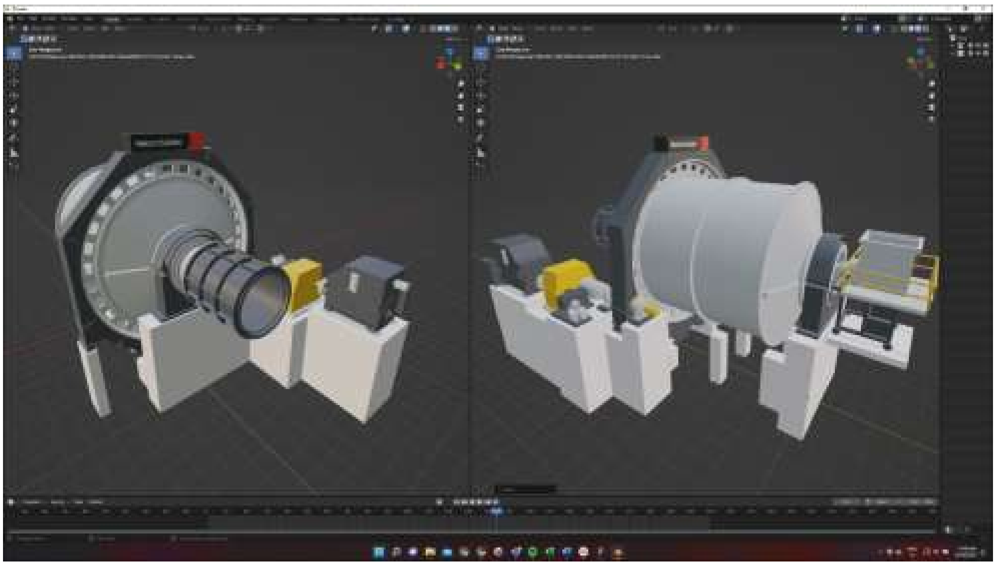

Figure 20. Blender Screen capture presenting the SAG Mill from two different angles (Juho Toratti, 2022).

The AA implementation focused on a simple concept. A singular part of an industrial enrichment process called a SAG mill. This SAG mill had two monitoring windows that displayed numerical to the user. There was also an option to assemble the mill, start the mill and move, rotate and scale the mill. These interactions were used to get the user familiar with how composite gestures work in the system. Also the voice commands were introduced in the beginning of the HoloLens 2 use where the system calibrated itself and the users could use UI dialogues with voice commands. The scope of the AA in the pilot study appeared to have been of an adequate, a larger prototype would have taken too long to use in the interviews.

The AA was done in Unity with Mixed Reality Toolkit 2 (MRTK) and deployed by Microsoft Visual Studio 2022. The AA used MRTK libraries for all the basic functionalities and interactions listed in Section 2.3.3. The mills rotation function and how the gauge and bar charts work in the AA were coded by me with Unity's built-in scripting engine using C#. Also the colors and used in the AA applications windows was decided by me and they are based on the *Modes* design system. Same base color palette and accents color was used as illustrated in Figure 17.

In the same week as the artifact was used in the interviews there was an event held at the Metso Outotec Espoo office where new potential technologies and technical developments are presented. I also had the opportunity to present my AA application and AR technology in this event for the participants. My presentation was a part of the GDT web application presentation booth in Metso Outotec Innovation Center. Image from this presentation can be seen in Figure 21. The finalized AA that was used as the interview artifact can be seen in Figure 22.

Figure 21. Artifact application presentation at Metso Outotec Innovation Center, Espoo, Finland (Piia Alavesa, 2022, with permission).

Figure 22. Picture taken of the finished AA application inside HoloLens 2. AA was used in presentation in Metso Outotec Espoo and as the finalized artifact in the interviews (Juho Toratti, 2022).

4. Research methodology

In this section of the research chapter, the study process including data collection method, pilot study, study setup and interview structure. Finally the chapter explains how the data analysis was conducted and initiated.

4.1 Data collection methods

This research used mixed research methods for data collection. Both quantitative and qualitative research methods were applied, but the thesis prioritized the qualitative research approach because it can bring forth the experiences and emotions of the users, allows for open-ended questions, and can answer ’how’ and ’why’ questions regarding the user’s interactions with the product. I had the advantage to design and develop the AA from scratch and study the anticipated experiences with actual professionals from the industry. With participants that are less experienced in the context, it can be harder to research because they have a conflict with imagining future use of technology that is contradictory to their current one (Von Hippel, 1986; Kukka et al., 2017). Research conducted by Yogasara (2011) implicates that when assessing UX in very early development phases of applications or products, it is helpful to include an artifact application into the process, which would function as the first step in addressing that problem. The design science research (DSR) method was discussed to be used when conducting this research. DSR was refrained from using because the original date for the thesis interviews was postponed from June to late September and thus several evaluations for the AA could not have been implemented in the remaining period. These are the justifications for why Anticipated User Experience (AUX) and mixed methods was chosen to suit this research rather than DSR.

4.2 Pilot study

Before conducting the actual interviews a pilot study for the interviews was done. The pilot study had two participants, one without previous experience with the technology and a participant with a work history in using Microsoft HoloLens 2 AR HMD. To be able to plan the amount and nature of questions, a preset period of 35-45 minutes per person per interview was planned before the pilot study with my thesis supervisors. This directed the amount of warm-up -and actual questions could be asked in the interview while considering the time spent with the AA. Warmup questions were also included to combat possible courtesy bias. To evaluate the interview process, two pilot interviews were conducted to evaluate the actual time required for the actual interviews compared to the time previously discussed. By interviewing both a novice and an experienced user of the new technology in the pilot study, I could make an evaluation of the average time that the interview questions and AA would take in the actual interviews. Both pilot interviews were supervised by my thesis supervisor Paula. After the pilot study, I received valuable feedback from my supervisor regarding the interview question structure and the overall study setup. Afterwards, questions were rephrased and organized, and some were omitted to fit better into the proposed time 37 frame. Omitting and organizing the interview questions was also done in anticipation of the interview’s open-ended -and probing questions. Based on these two interviews in the pilot study a median of 35 minutes per interview was discovered. Later this 35- minute time was increased to 45 minutes to accommodate room for potentially lengthy narratives posed by open-ended questions (Weller et al., 2018).

In the pilot study, there were also evaluates and findings on how to conduct and prepare the used technologies in the AA and interview. Observations and findings were made during the pilot study that was written down. These findings consisted of preparations that are needed before the use of HMD artifact which will be explained in more detail in the following section. These decisions were used to make the interview with the AA straightforward, fluent, and hygienic.

4.3 Study setup and interview structure

The study was conducted with the funding, approval, and request of Metso Outotec. Permission to record sound and analyze the interview data was confirmed by each interview participant individually with written and informed consent. A translation of the consent form from English to Bulgarian was done by the two different native Bulgarians with fluent English. A translated consent form was prepared to prevent the need to translate the form at the start of the interview and to provide trustworthiness to the consent form's validity. The participants were informed that at any point during the interview or AA they could abstain from answering or withdraw from the interview completely. Each participant also communicated the possibility to withdraw answers or ask additional questions after the interview was done. This was proposed in the consent form and contact information was provided. Participants also received a copy of the signed consent form, including the contact information of the researcher.

A time was reserved to set up the study setup before each interview. This setup included charging and turning on the Trimble XR-10 HMD, wireless bone conduction headphones Mobilus Labs mobiWAN_TR, laptop, and two audio recorders. Two recorders were used because one functioned as a backup in the occasion that one of them failed during the interview. Connecting the Trimble XR-10 and laptop to my mobile hotspot network. Network connection allowed the researcher and possible translator to view the point of view (POV) video stream of the interview participant using the Trimble XR-10 and give advice to them during the use of AA based on the video. Antibacterial wipes were also bought for the actual interview to clean the headset between users.

The interview started by introductions and explanation of the research purposes and why this research is important and thanking the interviewees for their participation. After this the consent forms were given out for both parties to sign and a translated consent form was ready if the interviewee asked for one. The actual interview started with six demographic questions warm-up questions ranging from age, title or position to their how their work hours are balanced between the office and on-site. After demographic questions a background questions related to use of AR technologies were asked. These ranged from earlier use of HMDs and MARs and what devices the participants had used if any and when they had used them. Also questions related 38 to safety and comfortability of their prior experience were asked. After the warmup, the participants were given the Trimble XR-10 and AA to use. Afterwards open-ended questions were asked from the participants regarding to what their first impression was, how did they perceive the safety and comfortability of the AA and what kinds of anticipated and new use cases they could imagine for the Trimble XR-10 HMD.

Physical 1-on-1 interview was not chosen only to allow them to use the AA use but also to emphasize interaction between interviewer and interviewee. This made it possible also to ask open-ended questions, where additional questions and information could be stated if a question was not understood properly, and this may avoid misunderstandings (Jordan, 2000). Probing questions could also be asked based on the conversation flow, and these could include questions related to the word pairs: safety and comfortability.

4.3.1 Artifact application

The AA was built with Unity to a Trimble XR-10 which is based on Microsoft HoloLens 2. The AA had basic AR interactions and gestures displayed for the participants to use and get familiar to. The reason to not producing a deeply detailed and defined use case that would solve a highlighted problem was to ensure the AA gave them a more open-minded approach on thinking about their feelings, experiences and anticipated use cases. This also helped to avoid the participants into focusing on pragmatic qualities rather than hedonistic ones. Additionally by this study design the researcher avoided putting the user into a predefined box that could have functioned as a limiting or restrictive factor on their anticipations of ideas and feelings emerging in the research. This allowed the users to think more freely and without the feeling of their ideas or emotions being contextualized by the physiological effect from a predetermined setting or pinpointed problem that the artifact would solve.

4.3.2 Interview participants

Participants were recruited through Metso Outotec and a total of 8 participants were interviewed and participated in using the AA. Four of the interviews were conducted with Metso Outotec personnel working closely with the GDT and the rest of the participants were clients working closely with Metso Outotec products on-site in Bulgaria. The participants age ranged from 28 to 55 ($\mu = 40{,}25$, $\sigma = 6.94$). The sampling in this research was narrowed to the participants with close working experience with the GDT or their close relation on working in the Industry 4.0 setting. This was done to align the research questions and purposes with the sample it is not possible or desirable to study everyone everywhere doing everything like Punch (1998) declared. Rather the study is using the concept information power proposed by Malterud et al. (2016) where the adequate saturation of sample size in qualitative research is created by dialogue quality, established theory, sample specificity and analysis strategy rather than sheer sample size. To avoid bloating the sample size with participants without correlation in the 39-research context the participants were selected by their qualities rather than just who was available. Therefore this study does not have participants without conceptual context to the subject. All interviews were conducted with a 1-on-1 interview principle and three interviews had a translator as the mediator. The choice to use of translator from English to Bulgarian was chosen to add trustworthiness, study rigor and this made the interview accessible and possible to more participants (Squires, 2009). Interview language with participants from Metso Outotec was Finnish. Finnish was chosen as it was the native language of both the interviewer and participant. All the participants were given a pseudonym and an individual number, Metso Outotec participants pseudonym is Specialist and Expert is used for Bulgarian participants.

4.4 Transcription and translation

The transcription was based on the notation done by Jefferson (2004) and can be seen in Appendix A. Poland (1995) argues that transcription quality comes from the word-to-word transcription method or at least restraining from omitting, mishearing, or intentionally twisting the spoken segments of the interview (Poland, 1995). A naturalized approach was chosen where the utterances of the interviewee are recorded with as much detail as possible. The detail of utterances is constructed not only with what is uttered but also the way. This can include tone of voice, emphasis, speed, timing and pauses in utterance (Oliver, Serovich, & Mason, 2005; Bailey, 2008). The naturalized transcript quality may vary from interview to interview depending on the used interview language and the need for a translator during the interview which is mentioned as a limiting factor in the discussion part of the research.

Visual data was not used in the interviewing process due to its challenging process and low research value compared to the time needed to be spent transcribing. Small talk conversations before and after the interview are also not included in the interview transcriptions due to their insignificance for the research. The choices in transcribing were done to suit and complement the research purpose and data analysis methods of this research. The reasoning for the introduction, explanation and revealing of the transcription process in high detail is to strengthen the claims and trustworthiness of interview data. Constas (1992) states that a higher degree of transparency with reasons and evidence must be available for inspection of the research process to increase analytical openness. Justification of analytical openness in research leads to more credible research and appeases the methodological rigor and analytical defensibility of qualitative research and analysis (Tilley, 2003). For the research's credibility and this research's progress to be a part of my academic dissertation I consider the justifications of research processes and the transparency in describing different parts like transcription as a necessity.

This research is cross-cultural as half of the interviewees were from a different culture from that of the researcher (Rogler, 1999). Following standards in transparency, informed consent, confidentiality with the interviewees, and protection of the gathered data obtained in the research leads to ethical research (Blaxter, Hughes, & Tight, 2010). The choice was made to translate the transliterations of Finnish interviews even as a novice researcher, but this was done because it widens the academic audience of 40 the research without necessarily jeopardizing its rigor or validity (Regmi, Naidoo, & Pilkington, 2010).

4.5 Data analysis methods

The data analysis was done only with qualitative data as the quantitative data collected (n = 8) was not significant to produce meaningful quantitative data analysis. Therefore the quantitative data is only documented, and it acts only as a support for this research. Implications may be drawn from the quantitative data, but this is highly just reflective in nature. Data analysis was started after the translation and transcription process.

All the initial qualitative data coding and was done by the author. The provide rigor and trustworthiness and eliminate cognitive biases to the qualitative findings were validated using Cohen's Kappa agreement test, where the categorization codes placed by both the thesis author and second observer who is a postdoctoral researcher and has plenty of professional experience with qualitative data research. There were two reasons for analyzing and conducting the coding scheme from the data alone. First there were time and resource constraints set by the project and master's thesis level research and secondly this ensured the author could develop and demonstrate his own research capability and minimize conceptual inaccuracies. AA observation and the open-ended answers in the interview were analyzed using general qualitative coding by (Charmaz, 2008). The coding method used is thematic analysis coding. Notations from the constructed transcripts were compiled into a separate file and numbered. This file and a spreadsheet containing the categorizations and codes was then shared with the second observer. This helped both validators to categorize them into their personal coding spreadsheet individually. Both validators had the exact same list with the same categorizations detected from the thematic analysis of the numbered transcript notations. The main point of data coding was to compile research categories from which the qualitative analysis and cross agreement validations can be made. The interview data was studied until no new categories were found i.e. data saturation was reached (Charmaz, 2008).

Qualitative content analysis was applied in the data analysis of the textual data. In content analysis research method the qualitative data gathered from the interviews can be categorized into valid and repeatable meanings in their context (Krippendorff, 2018). By successfully categorizing the conclusions and findings into a condensed form it gives meaning to the qualitative data without losing information in the process and allows for a systematic way to understand the phenomenon from the data (Krippendorff, 2018; Yogasara, 2014; Elo & Kyngäs, 2008). Elo & Kyngäs (2008) add that there also lie dangers in overly categorization of the data, which may affect the integrity of the information as the integrity of narrative materials may become lost. Elo & Kyngäs (2008) also mention that without supportive sections to the categorized and compressed data the original quality of data may be lost. In addition the format of research may have effect on the wording and spacing of the research. This thesis therefore tries to balance between the different spacing and word limitations of master's thesis format and the amount of compression and categorization of the qualitative data to produce the desired level of research.

In thematic analysis coding there are two different types how theme categories for the coding scheme are produced. First one is deductively found theme which is predetermined, and the other is inductive which are themes that emerge from transcripts made from the interviews with participants (Fereday & Muir-Cochrane, 2006). Two main categories in the coding were predetermined deductively by the word pairs used in connection with the open-ended questions from the interview. These two categories were the user's perceived safety and comfortability. The other categories and their sub-categories were curated from the extensive transcript data by inductive coding. Safety was further divided into a positive and negative sides. Comfortability was sub-categorized to give more accurate thematic representation on different codes. Motivators were similarly sub-categorized to positive and negative motivators. The last category of use-cases was also divided to two sub-categories regarding anticipated use cases and new use cases. From the list below a further description for the found coding categories can be perceived.

1. *Added safety*: user perceived added benefits on safety
2. *Reduced safety*: user perceived concerns on safety
3. *Comfortability*: related to size and weight
4. *Comfortability*: related to visuals
5. *Comfortability*: related to responsivity
6. *Positive motivators*: to use this technology: thoughts about what drives the motivation to use or develop the technology.
7. *Negative motivators*: to use this technology: thoughts about what drives the motivation not to use the technology and rather refrain from using or using something else.
8. *Anticipated use cases*: ideas related to the AR Geminex
9. *New use cases*: ideas outside of AR Geminex

5. Results

This chapter introduces the main results of the interviews and the different types of results in AUX context the AA and interview produced. The chapter is divided by quantitative and qualitative data sections. The rising themes from the interviews are also documented and how they were come up with. The first chapter outlays the quantitative data gathered from the interviews. In the second chapter the results of the qualitative data are presented, and a Cohen's Kappa agreement analysis is conducted. Additionally straight quotes from the transcripts are also included, outlaid and evaluated for their potential implications for the research which are then discussed in more coherent form in the discussion chapter.

5.1 Quantitative data

Data analysis was not done to the quantitative data gathered as the sample size was not enough to produce any meaningful results. Quantitative data gathered from the interviews is still presented to show transparency in how the research was conducted and what kind of data was gathered. Questions were asked from the interview participants how they perceived the use of AR or VR HMDs. Total of 4 participants had used HMDs prior to the interview, but only two participants remembered which HMD it was. One of both AR and VR HMDs were identified: Microsoft HoloLens and HP Reverb G2. If the participant had not used any type of HMD their answer was defaulted to neutral (3) in the Likert scales. This neutralization of answers causes non-response bias related to the other answers and therefore causes incentive not to analyze the resulting data, in fear of producing untrustworthy results. Below in the Table 1 the answers can be seen in Likert scale form. The answer is marked with an asterisk (*) if the answer was defaulted to 3. Total of 4 people had used AR or VR HMDs before the interview.

Table 1. Previous experiences regarding comfortability and safety with AR/VR HMD.

Likert	Comfortability	Safe
Strongly agree	1	1
Agree	3	2
Neutral	4*	1, 4*
Disagree	-	-
Strongly Disagree	-	-

All interview participants had used AR applications prior to the research. The experiences with AR applications were majorly experienced with MAR and only few had used an HMD AR application before. The applications ranged from Pokémon GO, QR Code Scanner, Google Translate, Snapchat, Skyview to AR flight scanner. From the eight participants only four knew what AR technology was and for the rest a quick description with example applications or application features were discussed.

5.2 Qualitative data

The qualitative data analysis was done by going through the transcription's multiple times until all thematic coding categories were identified from the transcript notations and no new category or sub-category themes appeared. After producing the thematic categories the transcript notations were coded into smaller quotes. These notes were then coded and distributed to a spreadsheet where each individual thematic coding acronym was placed. The constructed thematic coding scheme and individual coding categories were then presented.

Results between the analyzers were compared with Cohen's Kappa agreement analysis. For example in Cohen's Kappa agreement with two questions a 2 by 2 matrix is created. In this matrix there are two rows and two columns. Here the column cells represent how the researcher coded the quote notations from the numbered transcript notations and the row how the second observer coded, respectively. If both agreed and coded alike for the first category one point would be added to the cell in first row and first column of the matrix. If disagreed the point would be added to the cell where it matched the interpretation of both. This way the matrix concludes a diagonally shown agreements from top left to bottom right and any deviations on agreement interpretations can be seen outside this diagonal line.

The categorization from the transcripts yielded a scheme with four main categories and nine sub-categories. These categories served as the coding scheme categorizations that are presented in Table 2 with their respective code acronyms. This categorization scheme and scope focus on AUX was chosen to complement the study focus and structure. Possible categorizations with other perspectives or focuses are to be discussed later.

Table 2. Researchers coding scheme.

Main category	Sub-category	Code
Safety	Added safety	AS
	Reduced safety	RS
Comfortability	Size and weight	CS
	Visual	CV
	Responsivity	CR
Motivation	Positive motivator	PM
	Negative motivator	NM
Use cases	Anticipated use cases	AU
	New use cases	NU

The transcripts were read several times and notations which were out of the scope of this research focus were omitted. As an example, questions that were asked from the researcher after or before regarding other subjects like this quote:

> *"Mm- (.) I guess not much, probably what do you think about this or your own questions?" (Specialist A)*

These types of transcript notations were not included in the coding process as they were deemed outside the scope and focus of this research. After dividing the transcript into notations a total amount of 108 notations were obtained. These notations were then coded by both the researcher and second observer within the coding scheme matrix shown in Table 3. In this scheme matrix the agreement line can seen from the empty top-left corner all the way to the bottom-right where the last column for total amount of agreed notations are also seen.

The researcher and second observer agreed on 78 different codes for notations which resulted into an overall agreement percentage of 72,22% and a weighed Cohen's Kappa value of $\kappa = 0.67$ which considers guessing and shows a slightly deriving consistency in results as the calculated agreement percentage (Cohen, 1960). Here the weighed Cohen's Kappa value is presented, but it should be noted that the researcher's competence to rely on guessing would be in contradiction to the research rigor. Similarly the second observer who is a postdoctoral researcher, with professional experience with qualitative analysis, is most certainly devoid of just guessing the codes. For these reasons, the total of number of 15.1 or 14,03% that are expected to be by chance or a result of guessing, is substantially lower. Landis and Koch (1977) categorized the strength levels of agreement and in this categorization a Cohen's Kappa value between 0.61 and 0.80 is considered a substantial which also covers the calculated value $\kappa = 0.67$.

Table 3. Researcher and second observer's Cohen's Kappa agreement matrix

	Researcher										
Second observer	Code	AS	RS	CS	CV	CR	PM	NM	AU	NU	Total
	AS	5	2								7
	RS	1	8								9
	CS		1	5	1			4			11
	CV				4					1	5
	CR					2		1			3
	PM	2				1	14	1			18
	NM		1				1	13			15
	AU						3	2	9	3	17
	NU						2	1	2	18	23
	Total	8	12	5	5	3	20	22	11	22	78

5.2.1 Anticipated increase in safety

The first category from transcripts related to the users' anticipations in safety with the device with acronym AS. A total of five quotes were agreed upon to this category. The safety related anticipations evolved trough the interviews. This happened because the interviewees became increasingly familiar with different technologies and enabling attributes that the Trimble XR-10 provided, such as SLAM LIDAR for environmental awareness and geospatial anchoring of displayed data. Here below are great quotes regarding the KPI data and data in general and its positioning Expert #1 gave a great AUX quote for added safety which was particularly focused on AR technology:

> *"The good part is that you can see trough and you still can see doesn't matter what you see as visual there you can see what is on the background 45 of that aswell in case there is a safety concern you will see it trought the glasses (0.5) it's a good part of it" (Expert #1)*

There were also anticipated safety benefits that were discussed after the participants were given insight on how the environmental mapping worked. Expert #1 concluded that:

> *"Yeah another way that could be done, available access routes, safety issues yeah you know where to go and where to not go... and if undergound its eguipped with gas sensors and mm air sensors you can see like where is the gas so you bypass that area and just don't go there" (Expert #1)*

Also the participants were asked would they prefer MAR or HMD AR to be used on-site, Specialist #2 and Specialist #3 answered as follows:

> *"Hhh yeah it would be that one::: ((points to the HMD Trimble XR-10)) it probably is that, always when you would stare into a phone and also walk forwards it would not be good that way" (Specialist #2, Translated)*

> *"Yeah well we could like compare it into staring a phone and walking over there in the steet so that would also be probably quite unsafe, like that I- it should be taken care of" (Specialist #3, Translated)*

5.2.2 Anticipated reduction in safety

Here is a great quote from the anticipated reduction category RS. This point of view that corresponds with the transcript quotations mentioned in earlier in the anticipated increases in safety category AS.

> *"when you are focused on something else than the moving, well there the attention is fixated on the measurement values and functions and menus and what it has and if then you start walking that- there- well there I would see the biggest risk, hhh" (Specialist #4, Translated)*

He also added that after an explanation for the environmental awareness aspect was introduced that and a Likert scale question about safety was asked:

> *"Well hhh if we had to quickly throw some number here, some number if we give a four and that the 1... one in there in between would leave a room for that you wouldnt walk into some pit" (Specialist #4, Translated)*

And a plethora of other concerns were also drawn out because of the interviews. Those are listed here and discuss about that the superimposed data on the Trimble XR-10 might have affects to attention and focus.

> *"Well talking about my work I might get confused because it would attract my attention off of work and surroundings" (Expert #4)*

> *"Hhh, if no safety warnings are implemented into the application so that it would know continuously where you are and something would appear like, for me it feels like it would draw the attention away that you would quickly reverse and bump into things, you are more focused on the hologram things than the real environment" (Specialist #2, Translated)*

"Moving the focus from the surrounding danger it is not safe, because you are focused on what is happening in the HMD you may fall, you may not see the crane coming and that kinds of things" (Expert #1)

5.2.3 Perceived comfortability issues

The most notable coded and agreed notations regarding the comfortability. Here Specialist #3 commented when asked about how they would rate the comfortability aspect of the Trimble XR-10.

"In that there probably is hohowever more of a augmented reality like that you in a way still see this (0.5) see normally this real- real world into that is projected additional content like, that is probably helping here for that reason it would not so easily! this is just a guess" (Specialist #3, Translated)

The heaviness of the Trimble XR-10 was the leading subject and cause for a comfortability related issues and appeared in almost every interview. This subcategory CS of comfortability concerns also has the most agreed occurrences, five compared to CV with four and CR with two. It should be noted also that these issues were noted from a demo that was under 20-minutes of HMD usage during the interviews. There were quote notations regarding mentioned issue like:

"Heh, no but I think that maybe it feels too heavy or, but maybe in the end not that heavy when worn in the head, maybe I felt a bit clumsy with it :)" (Specialist #1, Translated)

"It is very heavy to use :)" (Expert #2)

5.2.4 Positive motivators towards the use of technology

There was positive feedback after the AA demo from the interviewees. There might be underlying implications that a first time use of new technology with AR HMD was the cause as the resulting comments appear very positive in nature. Here below are quotes of first impressions and comments after the AA demo was conducted that were also categorized into the PM category.

"Yeah!, Like you would use it here ((Metso Outotec office)) like if the job description would be that kind where you have to look at different things on sites then in addition that you have monitoring screens on the walls that you could go to that kind of environment virtually, then absolutely!" (Specialist #2, Translated)

"Mm first impression was really positive and mm encouraging and well I don't well l ha have alot of anything else to say but that yeah if you wont hurt yourself using then it its pretty ok, thumbs up!" (Specialist #1)

"Yea yeah! If it is like implemented in right routine and always the right people yeah! Why not that's quite advanced and hhh useful tool to have!" (Expert #1)

As the Specialist #1 was answering the Likert scale for rating comfortability it appeared as they possibly had underlying motive or outside effect to lean into a positive opinion.

"Hhh maybe 4 but therea are those regular helmets that are comfortable, yeah that is in a way.. lets be technology positive heh and lets say its a four heh" (Specialist #1, Translated)

"It is definitively cool heh that's cool" (Expert #1) "Very Nice!, oh yeah! well, I could imagine that it- it would be beneficial in like a modern factory" (Specialist #4, Translated)

"Yeahh hhh it was fun and we compare it to the HoloLens demo years ago this was lots and lots better in all ways" (Specialist #3, Translated)

"You feel like you are on a other planet when you are using it" (Expert #4)

And here the last three quotes were also specifically appearing as positive towards usage of HMD AR rather than MAR in the context of an Industry 4.0 and GDT. These comments could have also been anticipations of new use cases and categorized as such but are included here to amplify their resonance towards positive motivation in integration and use of this technology.

"I use a lot I am tracking all of the performance parameters via phone as well as with computer we have it that remote connectivity and this this will be I believe next level usage of the data" (Expert #1)

"oh yeah this is f-fun (3.2) like putting all those Geminex numbers there and everything Nice and so on! that would be really good yeah" (Specialist #2, Translated)

"immediately if you have to move, start to move then that is lots! better or like at least it has more potential compared to trying to look from a small phone screen or tablet" (Specialist #3, Translated)

5.2.5 Negative motivators towards the use of technology

Negative motivators that were identified from the transcripts. These transcripts from answers were usually after the question was asked that would they prefer to use MAR or HAR in general to the HMD.

"I liked it although I cannot figure out that I could use it in my work (Expert #4) "If we could have the same functionalities on a phone I would use phone instead because the size like phone is small. Can't think of any now for HMD to use" (Expert #3)

"Mm (1.5) I would say that currently the amount of data and detail it has is in a way not enough for the need to bring it on-site the contents and all diagnostics information what some device could give" (Specialist #1, Translated)

"Still phone would have the actuality? I don't know if that is right or ((usability?)) no attraction to use outside of workplace yeah the its more preferable than this one... if it has something all same functionalities as phone is having then ofcourse phone is easier to use and im used to this its with you all the time" (Expert #1)

Expert #1 added after this comment that that he would prefer and lean towards to use phone AR in the site rather than the HMD.

" I didn't want to destroy the idea of this one from the other point if it just that if you can do it on a phone I would go with phone because, because see like things I have said can be done on a phone aswell, like you have 3D model on you phone, augmented reality on a phone and you have all the data connected to 3D doesn't stop us from doing that on a phone." (Expert #1)

"I would prefer to use it with a computer because you are not doing the simulations on the plant but in the control room" (Expert #2)

A great outlaying comment was made by Expert #1 during the interviews, he proposed that technological advancements and adoption in their industrial contexts is hard because every person which the change concerns are suspicious and against it. He also added explained from the workers point of view that it is not even tied to what the change is, rather than just that there is something which changes.

"Yeah, because change management is hard, convincing people that to do the things differently is just hard heh Like just moving the people to the control room that was just, like I cant find the words to that they would find any excuse to not do that (0.2) any excuse, like they were saying 'no we don't want to go there so you are doing that for cut I mean cost savings to fire some people' no that is not the intention we are doing that to see if we can run the other mines from this place for example, we are testing that remote controlling part if its possible or not, they were not getting that and after that they were saying, 'okay but at the end the government is saying that if you are walking on the field you are going to the pension earlier If am not there I am not going to go pension earlier' this these kinds of things, after that we say okay lets try 12h shifts like 'we don't want to do 12h shifts its too long', now we moved to 12h and we say okay lets go back to the 8h 'no 12h is a lot better because have more free time' Its every change is stress, not only for operators or for work force its for management aswell. People who are forcing the change, having different type of stress, people who are going trough the change having different type of stress anyway both of them are having stress! Heh " (Expert #1)

5.2.6 Anticipated use cases

Anticipated use cases consisted of topics that related into the context of Geminex. There were total of nine coding's to the scheme that were agreed upon for experiences and expectations that the interviewees expressed. Interviewees talked about the data positioning and what kind of data they wished were to be presented in the actual finished product. These anticipations evolved trough the interviews as the interviewees became familiar with different technologies present in the Trimble XR-10. Here below are example quotes regarding the KPI data and data in general and its positioning:

> *"Well lets say that- like after a quick use I would like, like I said that for data... data presenting and especifially that its the right data in the right place and quickly accessible like- for that that is likely good like I wouldn't like start code- coding with it heh hhh" (Specialist #3, Translated)*

Three interviewees anticipated a potential display of combined Advanced Process Control (ACT) and DT data and values. ACT is a solution and product by Metso Outotec which can customize control applications and allows a stabilization and optimization for plant-wide production all the way to single-unit processes (Metso Outotec, 2022). The first expert also highlights that instead of using MAR or a tablet they would imagine seeing the data in an HMD.

> *"In principle yes would be helpful like instead of using a tablet you could use this and see the ACT information there and not only see it but you could also control them aswell" (Expert #3)*

The Expert #3 also added further down the interview that:

> *"Lets say that with in a wa- like based on a quick use I would say that like, like I said for data.. displaying the data and particularly that its the right data in the right place accessibly like for that purpose that is probably good like I wouldn't cod- heh code with ith heh hhh" (Specialist #3) "For example if you are wearing this and going to the plant you look at the flotation machine additionally to what I said you could see the efficiency of the machine aswell If you are using this and you have ACT and digital twin working in the background on this system and at the end it would tell us what is working well and what is not. And also having suggestive actions or something..." (Expert #1)*

Expert #1 continued with a more descriptive expectation and example from on-site operations:

> *"looking at the flotation machine like how the digital twin estimates how much is the actual numbers in the plant to having a table saying that this is the digital twin calculation and this is the actual... when you go to the mill site you see the mill simulation and the actual values from the mill" (Expert #1)*

Expert #3 gave an example for a new type of idea that is also fundamental in DT applications strategy. Where the DT saves and gathers historical KPI data, values and occurrences it derives simulations and predictive to future reference from there. Highly possibly a more immersive way would be to *time travel* back in time to see the occurrence in an immersive way with the HMD.

> *"But if you would just do viewing, you could go into the past with it and view how plant was in the past that could be and option aswell" (Expert #1)*

5.2.7 New use cases

During the interviews additionally to anticipated use cases for the Geminex context plethora of other experiences and ideas also rose. These included use cases related to safety with the HMD and a plethora of use cases for on-site work outside the monitoring and process control operations.

> *"and if undergound its eguipped with gas sensors and mm air sensors you can see like where is the gas so you bypass that area and just don't go there it can (0.2) see like there is many fields it can be used this tool for but yea you need to justify what additional it can give over the tools available now, that's the key if you cant find additional things" (Expert #1)*

> *"At work it is yes to use it, but its more beneficial using it for trainings or for the new projects coming and wish to have more details than it is having now For example if you have new equipment delivery it needs to be assembled here like equipment to be assembled with using this you would see how you would assemble it and you would do it by wearing this" (Expert #1)*

> *"It would be beneficial in if you want to put new pipelines, you could determine where they would go and avoid any constrainted areas you cant pass it trough" (Expert #2)*

People also suggested in the end when they got familiar with the environmental detection in the HMD that it could be used to avoid safety hazards. These types of new use cases ranged e.g. from giving presentations, training, remote assistance, highlighting approaching danger and highlighting things you can hit your head to.

> *"((so maybe useful in training or?)) Yeah that's the thing. Training, remote assistance, guiding the unprofessional. . . not unprofessional, less experienced operators or less experienced fitters to do the things" (Expert #1)*

> *"but if you have for example on place workstation like remote control room yea I do not see the problem having it looking at opportunities what you can make based on this. . . " (Expert #1)*

> *"Maybe it would be cool to have some indication on top of this if there is something on the way " (Expert #4)*

6. Discussion

In this chapter the research findings from results are elaborated on and evaluated. While the results chapter focused on outlaying the results of this research in this chapter those results are analyzed and explored with the inclusion of related work to support and answer research aim and questions. The chapter starts by presenting the underlying problem in every new technology, but emphatically present in technologies under the umbrella term XR and draws conclusions from the results chapter. In the second section the faster evolution of different technologies related to their use cases and UX are discussed. In the third section of this chapter the limitations of this research are highlighted and documented and after limitations the implications for future works are discussed.

6.1 Conclusions of the results

Here in this chapter the results are discussed, and their implications are drawn into a coherent and respective category. From the listed quote notations that was present in the results relationships to the related work of this research are drawn. A premise is conducted which helps to determine if in the end this research could answer both of the research questions.

6.1.1 Causality of novelty effects

First impressions can dictate a mood to interview processes, perceived positivity or negativity towards the technology can have an effect in how the interviewee perceives the follow-up questions or sees themselves anticipating their use in the future. As this study uses new technology, it is susceptible to novelty effect which may affect the first impressions of the technology by enhancing motivation of the users which may fade over time after prolonged use of said technology (Jeno, Vandvik, Eliassen, & Grytnes, 2019). Similar conclusions were made in study conducted by Hopp & Gangadharbatla (2016) with AR advertisement context. Also a study done by Hamari et al., (2014) outlines additional three studies which point to a direction that gamification could also be the cause for increased novelty effect, but arguably in a considerably lesser extent than the actual AR technology used. Transcription done naturally also gave more insight on what type of mood the answers were given and gave more accurate way of coding the transcript data. As there happens to be overly positive tones and rise in intonation after the interviewees first impressions of the technology was discussed it implicates that novelty effect influenced them. This positive emotive effect can be easily observed from the quotes in the category Section 5.2.4.

6.1.2 Perceived prolonged use of device

The main comfortability issues that were found in the results were related to the heaviness of the HMD. Participants discussed that the HMD was too heavy for use and commented that it would be impossible to use the HMD for the whole working day on-site. This issue was also anticipated and discussed to be solved in the future when the AR HMD technology evolves and becomes smaller and lighter.

6.1.3 Anticipated and new use cases

Plethora of new use cases were distinguished by using the AUX method of study conjoined with the use of an actual artifact application. Others regarded the integration of aspects from the UI from the traditional GDT and others outlaid new proposals on how to make the data displayed on-site safe to utilize. A recurring theme after the environmental mapping feature was introduced to the participants were the imagination of highlighting different dangers from the on-site environment like protruding objects, missing pieces of grids on the walking surfaces and potentially hazardous places. When given the right tools and explaining the technology the participants imagined more practical uses to increase safety which were additional to what they could do with their MAR and HAR on-site. These also included additional use-cases the participants imagined for other purposes than GDT simulation, data display and usage. and The given example of the AA was great in showing the possible basic features that the participants could then use as a basis to anticipate future uses for the Trimble XR-10. As the AA was spatially restrictive and anchored the users imagined that the showing KPI and numerical data straight in the converged virtual and physical machines would be possible to implement in a way where the UI elements superimposed into their view would appear only on the actual machinery to appear in its right place and to be clear from the user's view, so they could traverse on-site without the worry of falling or bumping into things.

From the results a use case related to the web GDT was proposed. In addition to the representation of the site data in the machinery on the site, they imagined an immersive functionality that would allow them to go back in time, to look at the site in certain time possibly to learn from the KPIs and data from that point in time for future simulation purposes. It can be perceived that the convergence relation of DT and AR technology proposed in Figure 10 and discussed in could be useful in understanding this type of AUX where the physical and virtual space are converged.

Simultaneously the environmental highlighting of dangers and on-site geospatial data were deemed to be important while on-site operations are conducted. Similarly like in Section 2.5 of from related work this type of real life scaled environmental representations were discussed and anticipated to provide more value rather than 2D UI elements.

AR can bring the virtual and physical counterparts together by continuously integrating with the site or systems data into the AR DT applications. On par with the ability to show data e.g. KPI's, or numerical data, warnings straight in the physical machines on site, this makes it also possible for telepresence, the user can feel that they are in the site remotely even if they are far away. 1:1 scaled constructs of the actual environment make it easier to understand the whole process and any inter dependencies of system components on-site (Tao et al., 2018; Lasi et al., 2014; Delgado et al., 2020).

Additional use-cases rose also from the study. A plethora of cases regarding the assembly instructions for parts that arrive on-site. Participants imagined that the HMD could be used for remotely assisting people who are working on-site by providing camera view of the operator. Also remote conferencing and communications with the vendors were imagined and anticipated. Participants also imagined that the device could potentially measure different dangers like any gas leaks present or hazardous environments. All of these additional use-cases that were not strictly related to the Geminex were potential cases for future studies and technologies.

6.2 Evolution of new technologies

In today's technological advancements there is a problem with how technological advancements are overshadowing the actual need and use for the technology. This poses problems for the technological development into fully commercialized products or services. To its technological advancement nuances in user experience, usability and use cases were severely missing. This also fits into the narrative in Section 4.1 and study conducted by Yogasara (2011), that most UX frameworks and evaluation techniques tend to assess an already existing or functional prototypes. Same implications can be derived from this research but as AR being the new technological advancement. Even if this research reacted by studying AUX with an early developmental artifact, the technology and basic UX heuristics for AR applications are trailing behind the actual technological advancements. This may in turn proposes challenges for the technology's advancement as a commercialized application platform and people may not see the benefits in adoption or integration of new technologies.

This research is also outlined by the technology advancement problems as participants of this study could not see the potential of the new technology because, they were suspicious on what additional benefits it could give them in their work. This affected the interviewees to prefer a technology and UI that was already familiar and accessible to them. These findings agreed also with Sánchez-Adame et al. (2020) where elements present in familiar UIs were preferred over the newer ones. Like suspected earlier the participants could not imagine that this technology would be widely available in the future for them in a familiar way as smart phones were a just a novelty technology before they were widely adopted for commercial use. Similarly like the conclusion in research conducted by Yogasara (2011) the negative AUX were nearly exclusively related with comparison to the existing product and the positive AUX to the anticipated and desired product. This also highlighted the participants willingness to have the anticipated use cases integrated to MAR rather than the HMD.

The results also indicate that different interviewees wanted the AA to show and control the data from ACT in the site on par with the data provided by the GDT simulations. Similarly accurate and real-time KPI data that is gathered from the hard and soft sensors on the site was deemed important to see when looking towards the machine related to the data. These findings propose that the participants focus here was mainly in the physical product data rather than the virtual data generated by the GDT and DT in general. This is in line with the findings from the use mediums where the participants wanted to use familiar technology, but in this case they imagined a use of the physical data rather than virtual from DT which was familiar data from ACT. These agree with the findings from research done earlier by Tao et al. (2018) on Digital twin-driven product design, manufacturing and service with big data.

These findings and behaviors subsequently with the problems that people mentioned regarding comfortability focused their experiences on pragmatic qualities of the product in the interviews. Also the participants perceived focus of negative AUX could relate to the overemphasis of the pragmatic qualities and aspects of the imagined product in its early developmental phase compared to familiar products like concluded

6.3 Limitations

The possible limitations that were recognized are discussed in this section. Regarding the whole research there are a possible limitation regarding the thesis focus due to limited amount of research done. Additionally limitations caused in transcription, translation, sample size and quality, novelty effects and in transcript coding are discussed. Lastly future work and their implications are outlaid in the final section of this chapter.

6.3.1 Thesis focus

The three focus areas of this thesis are each on their own recent topics to study and use in academical writing. Hence this produces a problem to credibility and research rigor as many of the references and research done prior to these focus areas are scarce. This problem enhances when these focus areas are used in conjunction with each other as already limited amount of academic research done is focused to procure the theme of this research. This limitation must be distinguished for transparency and as a request to the academic audience to conduct more research of these focus areas. Using AUX that for this research Gegner et al. (2012)

6.3.2 Transcription

Transcribing process is usually left without mention and justification in thesis-level studies or only the bare minimum of the process is explained. This is done even though naturally qualitative research gains rigor and reliability from the transparency of research processes including interview transcribing (Braun & Clarke, 2006). Even though this research tries to have full transparency in transcribing process it is limited by the extent that fits into a master’s thesis’ level of research. To respect NDA, GDPR, and the agreements with the interviewee, that the data would stay between the parties involved in the interview, a third party could not be involved in making the transcriptions. For future reference, a permission to use professional in transcription should be asked from the participants. These are the reasons why the transcribing process for this research was done by me and not a professional transcriber. By not using a professional transcriber there might be nuances and aspects that were lost in the transcribing process. You have stop and think that you have enough for the context like Blaxter (2010) mentioned in his book, *How To Research*.

> *"Most researchers have to compromise their practices to fit into the time and other resources available for their studies. Doing research is, therefore, about producing something that is good enough rather than providing the final word of truth on a particular topic” (Blaxter 2010, pp. 14)*

For this thesis purpose like Blaxter said in an earlier quote I keep that transcribing level is adequate for master’s thesis research but in addition I would argue it may pose limiting factors to the research rigor.

6.3.3 Translation

There was a need for an interview translator with three of the participants in Bulgaria. There is a possibility that parts of the interview questions and answers may have been slightly affected or lost because of the translation process because the native language could not be used in the interview (Squires, 2009). Also the process of transcribing these interviews with a translator it is not possible to conceive a naturally transcribed and accurate transcription. Even if I can perceive utterance, emphasis, speed, and timing in the transcribing process I have no language knowledge to justifying contextuality or meaning. I can only make limited assumptions based on the tone of the original answers on how they answered or perceived the question and how the translator interpreted and mediated the answer.

In two of these interviews, the translator had a hierarchically higher position relative to the interviewees, which may have affected the answers or the demeanor of the interviewed person and caused social desirability bias. There was also one interview where the translator was a different person, and the participant had no earlier social relationship with the translator. This may have also had a similar effect on the demeanor and answers but arguably not to same extent as in the interviews with the other translator. Although both the interviewer and translator were fluent in spoken English, neither was a native speaker, which is why all the interviews in Bulgaria have the possibility of verbal mistakes projected to the interviews. One of the interviews was done with a different translator and it may pose inconsistencies between the interviews, which threatens the trustworthiness of qualitative research and may subsequently affect research rigor and conclusion quality (Squires, 2009; Edwards, 1998). An optimal technically and conceptually equivalent translation could not be achieved in this study. Even though the translators were conceptually equivalent to the mining industry terminology they did not possess the same level of conceptual equivalency with terminology related to AR and DT. Therefore there is a risk in cross language qualitative research translations as conceptual equivalency may be lost in the process or words used are susceptible to deviations (Frederickson, Acuña, Whetsell, & Tallier, 2005; Gee & Gee, 2007; Temple & Young, 2004).

6.3.4 Sample size and quality

For this thesis research level it is hard to get adequate number of qualifying participants that pose great information power for this type of narrowly focused research. Sample size can propose limiting problems for the quantitative part of this thesis as only eight participants could be recruited. It could be argued that the data saturation had not been reached and it is highly possible that eight specific and pinpointed participants were not enough in this study to produce a rigorous study. This claims basis could only be confirmed by doing the same type of study again with a larger participant sample size. Also the fact that half of the interviewees were Metso Outotec personnel they may have had underlying effects or bias towards being more positive on how they perceived the integration, development and adaptation of this new type of technology. For this reason also the pseudonyms for the Metso Outotec personnel are Specialist and for personnel from Bulgaria Experts.

6.3.5 Novelty effects in technology

When using new technology there is a motivational effect caused by novelty effect. This can have a positive effect to the participants mindset towards the new technology and have an effect how they answer the interview questions after evaluating a new technology (Jeno et al., 2019). This could be mitigated by conducting study where the participants are familiar with the technology before the interview. This could be achieved by only interviewing technology proficient participants or using approach where the technology is first used before the actual interview to get used to it and lessen the probability of novelty effect in the second time use.

6.3.6 Coding the transcript data

As this is master's thesis level research, the transcriptions were coded, and themes identified by just me person and the analysis agreements only cross-checked once. There might have been effects on the results as the second observer was also familiar with the thesis concept. Even if the Cohen's Kappa agreement analysis was used and implications and agreements were observed, it's not adequate in providing perspectives from more than two people with different areas of expertise. Two researchers can also give a subjective perspective and alternative interpretation which might be degrading to the research rigor and results (Sandelowski, 1995). To further enhance concept production and help with coding issues it would require a panel of experts to assess the data (Elo & Kyngäs, 2008).

6.4 Future work

This thesis acts as a check point for a qualitative anticipated user experience research that utilizes early developmental artifact and gamification design method to assess the need of researching early technological integrations and adaptations of new novelty technologies. This thesis suggests that this type of research perspective was successful in solving early developmental problems that are caused by new integration and adaptations. As this thesis focused on the users AUX a subcategory of UX there was not enough time to study the user's affordances with AR HMDs and the GDT applications UX.

For future work it is recommended that more research should be done that use both the AUX and a developed artifact. Based on this research and how the artifact was used, it proposes that a more traditional and continuous artifact evaluation with the interview participants should be adapted to whenever plausible. This could alleviate problems from the novelty effect that may have distorted the research results implicated from the interview data. This also would confirm that AR artifact usage has the same implications in diminishing motivation during the prolonged use of them.

Artifact and specificity may affect the AUX study research results. Therefore it should be studied what kind of implications and affects artifacts specificity has in AUX studies and what is relevance and implications of overly specified and developed artifact. For instance, is this restrictive to the study participants ability think open-minded or outside the imaginary boundary box, which the too specific artifact may create. This might hinder the participants ability to anticipate their feelings and experiences before, during and after the use of an artifact. For its significance and determination in future works this thesis proposed a term: Artifact Specificity Constraint (ASC).

The data gathered from the interviews was saturated with very specific and thorough thematic coding that complemented the chosen study method which also produced substantial agreement results with a seasoned qualitative researcher. Additional research could be done with different type of thematic coding for the gathered interview data to conclude more thematic viewpoints that this open-ended questionnaire study provided. For future reference, different thematic coding categorizations used in the research could bring additional views on different aspects relative to what this study already identified.

For future reference it should be researched how introduction of an artifact may affect the participants AUX of a product related to just using interview without it. This would solidify the statements and implications that this study proposes and also prove additionally the need for a developed artifact in early development phases. Study could be conducted by dividing large number of participants into two random groups, where one group uses the artifact, and the other does not and comparing the results between them afterwards. Other way to study would be to ask the same questions from the study participants before and after the use of the artifact and collect any additional data discovered.

The UX and UI layout designs were implemented to the web application version GDT during this thesis project. To research how the users perceived the new gamified layouts should be done in the future work. The workshops documented and used combined with the finalized layouts were so comprehensive that they contributed to a scientific paper of their own. From these published papers preliminary title for the workshop paper is *Designing gamified interfaces for a process digital twin in mining context through a series of expert workshop* (Alavesa, Alavesa & Toratti, 2023) For this study scope it was impossible to conduct and include research from this topic as well, as both could the expert workshops and the design implementations could have been a thesis or paper on their own.

Later also paper regarding this thesis subject will be published. This paper written by Toratti & Alavesa (2023) uses a tentative title called *Using anticipated user experience on early development phases of Augmented Reality applications in Industry 4.0 technologies.* To be submitted to *Augmented Humans*.

7. Conclusions

This thesis presents a qualitative anticipated user experience research, with the inclusion of early development artifact and gamification design method to research early technological integration and adaptations, to achieve two goals. The first was to understand the fundamental requirements for industries on integrations and adoption of AR technology. The second was to determine how applications user interface integrations to AR can be guided using AUX in the early development phases. The data resulted in significant findings on what kinds of anticipated use cases and solutions for how the DT or other applications related to the industrial field should be developed when they are to be integrated to AR. New findings were discovered during the interviews as the questions and discussions directed the interview to determine what the participants anticipated for their work. Valuable feedback from the AUX study with the professional participants resulted in knowledge and mutual understanding on what is needed and how safety and comfortability could be also solved with the early developmental version for the actual application and system. This thesis outlaid a coding scheme with nine categories. These categories were thematically coded from the transcripts for this specific focus area to produce Cohen's kappa agreement results with second observer. These coded categories can be utilized as a reference in similar types of research.

The thesis findings implicated that there is a demand for artifact and AUX usage in the early phases of development to help in the user's evaluation for future products and their experiences with them. This reduces the possibility of delayed user experience assessment which has the possibility to result in unfavorable consequences in development and quality. When studying a new technology adaptations and integration's there is a need for inclusion of the actual professional users in the study to procure and study the actual needs and requirements before development, rather than resorting to speculating them. These findings co-agree with the findings in study conducted by Yogasara (2011). This thesis works to further assess the problems in integrating new types or existing technologies to the industry in a new AR format and how these integrations should be studied and conducted with the help of gamification, AUX and artifact. By using previous knowledge on how artifacts are suitable to study AUX I was able to incorporate and foresee more accurately on what kinds of problems may lie in integrations of AR applications to the industry. It appears that also the AR applications and technological solutions are as susceptible to the problems in very early development than other applications and technological solutions and benefits from an AUX study that is in combination with an artifact use. Additionally HMD AR technology has a novelty effect to the users which proposed problems on how the participants anticipation towards the future use of the technology could be too positive. This was proposed to be solved in using people familiar with the technology.

The conducted interviews and their results presented same implications as other studies earlier even the use medium had changed. The user's susceptibility or motivation to use the new technology was limited by different factors. One of the most noticeable problems related to the artifacts AUX use was the potential long use of the Trimble XR-10 HMD, but positively users also anticipated or imagined that the experience would be solved in the future technology.

During the start of the interviews a trend was recognized where the first concerns about safety were usually towards reduction of safety on-site. This happened because the participants did not know that the device had environmental awareness trough SLAM and

LIDAR. After discussing that the device could map the surrounding environment and potentially indicate these dangers on-site the following AUX answers and comments usually evolved and leaned towards AS.

The thesis offers complementary continuation regarding the AUX studies with the use of artifact, integration of web application to augmented in industrial setting while using gamification as design methodology, and how artifact quality may affect interview participants perceptions of the technology. In addition an extension on the use of anticipated user experience combined with artifact to provide new research perspective with the addition of gamification as design method to help with the evaluation of actual user experiences in early development phases of novelty technologies. This is in line with research suggestion by Yogasara (2014) where new types of technologies are proposed to be studied with the AUX method to research and new early assessment techniques for user experience could be created. Also a design methodological step was made in integrating gamification design method into an industrial serious game application context. Bringing this design method to industry and using it as the main methodology in UI/UX designing allowed for the different approach to help motivate users and provide a better user experience. This study proposes that the participants ability to anticipate their feelings and experiences before, during and after the use of an artifact may be affected by the artifact specificity. For its significance, this research proposes a term: Artifact Specificity Constraint (ASC). Without the inclusion of this artifact prototype dubbed in this research as AA, it would have been practically impossible to conduct and gather actual AUX interactions between the user and the device for this research. The thesis also proposes a relationship between how the description of DT and virtual reality continuum proposed by Milgram & Kishino, (1994) could be combined. This combination is proposed as a converged relations model for virtual reality continuum and digital twins in Section 2.5 Figure 10. This model helps understand and lay basis for future references for how these two technologies are converged with each other.

References

Akçayır, M., & Akçayır, G. (2017). Advantages and challenges associated with augmented reality for education: A systematic review of the literature. *Educational Research Review, 20,* 1-11. doi: https://doi.org/10.1016/j.edurev.2016.11.002

Alavesa, P. (2018). Playful appropriations of hybrid space: combining virtual and physical environments in urban pervasive games. *Playful appropriations of hybrid space: combining virtual and physical,* 30-35. http://urn.fi/urn:isbn:9789526221380

Alce, G., Ternblad, E.-M., & Wallergård, M. (2019). Design and evaluation of three interaction models for manipulating internet of things (iot) devices in virtual reality. *Ifip conference on human-computer interaction* 267–286.

Alvarez, J., Djaouti, D., et al. (2011). An introduction to serious game definitions and concepts. *Serious games & simulation for risks management, 11*(1), 11-15.

Andriessen, J. (1978). Safe behaviour and safety motivation. *Journal Of Occupational Accidents, 1(4),* 363-376. doi: https://doi.org/10.1016/0376-6349(78)90006-8

Apple. (2–22). iPhone 14 pro and iPhone 14 pro max - apple. From https://www.apple.com/iphone-14-pro/ (Accessed: 11 November 2022)

Arhippainen L (2009) Studying user experience: issues and problems of mobile service – Case Adamos: user experience (im)possible to catch? Doctoral dissertation, University of Oulu.

Aukstakalnis, S. (2016). Practical augmented reality: A guide to the technologies, applications, and human factors for ar and vr. *Addison-Wesley Professional.*

Bailey, J. (2008, 02). First steps in qualitative data analysis: transcribing. Family Practice, 25(2), 127-131. From https://doi.org/10.1093/fampra/cmn003 doi: 10.1093/fampra/cmn003

Begault, D. R. (1999). Auditory and non-auditory factors that potentially influence virtual acoustic imagery. *Audio engineering society conference: 16th international conference: Spatial sound reproduction* (pp. 3).

Blaxter, L., Hughes, C., & Tight, M. (2010). How to research. *McGraw-Hill Education (UK)*.

Boas, Y. (2013). Overview of virtual reality technologies. *Interactive multimedia conference* (part 2013, pp. 2).

Bolas, M. T. (1994). Human factors in the design of an immersive display. *IEEE Computer Graphics and Applications, 14*(1), 55–59.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative research in psychology, 3*(2), 77–101.

Butz, M. V., Sigaud, O., & Gérard, P. (2004). Anticipatory behavior in adaptive learning systems: Foundations, theories, and systems (part 2684). *Springer.*

Carlson, K. J., & Gagnon, D. J. (2016). Augmented reality integrated simulation education in health care. *Clinical Simulation in Nursing, 12*(4), 123-127. From https://www.sciencedirect .com/science/article/pii/S1876139915001012 (Special Issue: 62 Gaming) doi: https://doi.org/10.1016/j.ecns.2015.12.005

Chan, A. P., & Chan, A. P. (2004). Key performance indicators for measuring construction success. *Benchmarking: an international journal.*

Charmaz, K. (2008). Grounded theory as an emergent method. *Handbook of emergent methods, 155,* 172.

Chatzopoulos, D., Bermejo, C., Huang, Z., & Hui, P. (2017). Mobile augmented reality survey: From where we are to where we go. *IEEE Access, 5,* 6917-6950. doi: 10.1109/ACCESS.2017.2698164

Chen, L., Day, T. W., Tang, W., & John, N. W. (2017). Recent developments and future challenges in medical mixed reality. *2017 ieee international symposium on mixed and augmented reality (ismar)* (pp. 123–135).

Cidota, M. A., Lukosch, S. G., Bank, P. J., & Ouwehand, P. (2017). Towards engaging upper extremity motor dysfunction assessment using augmented reality games. *2017 ieee international symposium on mixed and augmented reality (ismar-adjunct)* (pp. 275–278).

Constas, M. A. (1992). Qualitative analysis as a public event: The documentation of category development procedures. *American Educational Research Journal, 29*(2), 253–266.

Deci, E. L., Nezlek, J., & Sheinman, L. (1981). Characteristics of the rewarder and intrinsic motivation of the rewardee. *Journal of personality and social psychology, 40(1),* 1.

Delgado, J. M. D., Oyedele, L., Demian, P., & Beach, T. (2020). A research agenda for augmented and virtual reality in architecture, engineering and construction. *Advanced Engineering Informatics, 45*, 101,122.

Deterding, S., Khaled, R., Nacke, L. E., & Dixon, D. (2011). Gamification: Toward a definition. *Chi 2011 gamification workshop proceedings* (part 12, pp. 9-10). Vancouver BC, Canada.

Edwards, R. (1998). A critical examination of the use of interpreters in the qualitative research process. *Journal of ethnic and migration studies, 24(1),* 197–208.

Elo, S., & Kyngäs, H. (2008). The qualitative content analysis process. *Journal of advanced nursing, 62(1)*, 107–115.

Evans, G., Miller, J., Pena, M. I., MacAlliste60panish60tWiner, E. (2017). Evaluating the microsoft hololens through an augmented reality assembly application. *Degraded environments: sensing, processing, and display 2017* (part 10197, pp. 101970V).

Fereday, J., & Muir-Cochrane, E. (2006). Demonstrating rigor using thematic analysis: A hybrid approach of inductive and deductive coding and theme development. *International journal of qualitative methods, 5*(1), 80–92.

Frederickson, K., Acuña, V. R., Whetsell, M., & Tallier, P. (2005). Cross-cultural analysis 60panishceptual understanding: English and spanish perspectives. *Nursing Science Quarterly, 18*(4), 286–292.

Gee, J., & Gee, J. P. (2007). *Social linguistics and literacies: Ideology in discourses.* Routledge.

Gegner, Lutz & Runonen, M.. (2012). For what it is worth Anticipated eXperience Evaluation. *8th International Conference on Design and Emotion: Out of Control - Proceedings*.

Glaessgen, E., & Stargel, D. (2012). The digital twin paradigm for future nasa and us air force vehicles. 53rd aiaa/asme/asce/ahs/asc structures, structural dynamics and materials conference *20th aiaa/asme/ahs adaptive structures conference 14th aiaa* (pp. 1818).

Gopalan, V., Bakar, J. A. A., Zulkifli, A. N., Alwi, A., & Mat, R. C. (2017). A review of the motivation theories in learning. *Aip conference proceedings* (pp. 020043).

Grieves, M. (2014). Digital twin: manufacturing excellence through virtual factory replication. *White paper, 1(2014),* 1–7.

Grubert, J., Itoh, Y., Moser, K., & Swan, J. E. (2017). A survey of calibration methods for optical see-through head-mounted displays. *IEEE transactions on visualization and computer graphics, 24*(9), 2649–2662.

Hamari, J., Koivisto, J., & Sarsa, H. (2014). Does gamification work?–a literature review of empirical studies on gamification. *2014 47th hawaii international conference on system sciences* 3025–3034.

Hopp, T., & Gangadharbatla, H. (2016). Novelty effects in augmented reality advertising environments: the influence of exposure time and self-efficacy. *Journal of Current Issues & Research in Advertising, 37*(2), 113–130.

Hou, L., Wu, S., Zhang, G., Tan, Y., & Wang, X. (2020). Literature review of digital twins applications in construction workforce safety. *Applied Sciences, 11*(1), 339.

Huo, K., Cao, Y., Yoon, S. H., Xu, Z., Chen, G., & Ramani, K. (2018). Scenariot: Spatially mapping smart things within augmented reality scenes. *Proceedings of the 2018 chi conference on human factors in computing systems* (pp. 1–13).

Huynh, D., Zuo, L., & Iida, H. (2016). Analyzing gamification of “duolingo” with focus on its course structure. *International conference on games and learning alliance* (pp. 268–277).

ISO 9241-210, I. (2010). Ergonomics of human system interaction-part 210: Human-centered design for interactive systems. *International Standardization Organization (ISO).* Switzerland.

ISO 22400, I. (2014). 2—automation systems and integration—key performance indicators (kpis) for manufacturing operations management—part. 2: Definitions and descriptions. *International Organization for Standardization (ISO):* Geneva Switzerland.

Jaboyedoff, M., Oppikofer, T., Abellán, A., Derron, M.-H., Loye, A., Metzger, R., & Pedrazzini, A. (2012). *Use of lidar in landslide investigations: a review. Natural hazards, 61(1),* 5–28.

Janin, A., Mizell, D., & Caudell, T. (1993). Calibration of head-mounted displays for augmented reality applications. *Proceedings of ieee virtual reality annual international symposium* (pp. 246-255). doi: 10.1109/VRAIS.1993 .380772

Jefferson, G. (2004). Glossary of transcript symbols. *Conversation analysis: Studies from the first generation,* 24–31.

Jeno, L. M., Vandvik, V., Eliassen, S., & Grytnes, J.-A. (2019). Testing the novelty effect of an m-learning tool on internalization and achievement: A self-determination theory approach. *Computers & Education, 128,* 398–413.

Jones, J. A., Swan, J. E., Singh, G., & Ellis, S. R. (2011). Peripheral visual information and its effect on distance judgments in virtual and augmented environments. *Proceedings of the acm siggraph symposium on applied perception in graphics and visualization* (pp. 29-36).

Jones, J. A., Swan, J. E., Singh, G., Kolstad, E., & Ellis, S. R. (2008). The effects of virtual reality, augmented reality, and motion parallax on egocentric depth perception. *Proceedings of the 5th symposium on applied perception in graphics and visualization* (pp. 1–14). New York, NY, USA: Association for Computing Machinery. From https://doi.org/10.1145/ 1394281.1394283 doi: 10.1145/1394281.1394283

Jordan, P. W. (2000). Designing pleasurable products: An introduction to the new human factors. CRC press.

Ke, S., Xiang, F., Zhang, Z., & Zuo, Y. (2019). A enhanced interaction framework based on vr, ar and mr in digital twin. *Procedia CIRP, 83,* 753-758. From https://www.sciencedirect.com/science/article/pii/S2212827119307176 (11th CIRP Conference on Industrial Product-Service Systems) doi: https://doi.org/10.1016/j.procir.2019.04.103

Kim, S., Nussbaum, M. A., & Gabbard, J. L. (2016). Augmented reality “smart glasses” in the workplace: industry perspectives and challenges for worker safety and health. *IIE transactions on occupational ergonomics and human factors, 4*(4), 253–258.

Krippendorff, K. (2018). Content analysis: An introduction to its methodology. *Sage publications.*

Kukka, H., Pakanen, M., Badri, M., & Ojala, T. (2017). Immersive street-level social media in the 3d virtual city: Anticipated user experience and conceptual development. *Proceedings of the 2017 acm conference on computer supported cooperative work and social computing* (pp. 2422–2435).

Laamarti, F., Eid, M., & El Saddik, A. (2014). An overview of serious games. *International Journal of Computer Games Technology*, 2014.

Landis, J. R., & Koch, G. G. (1977). The measurement of observer agreement for categorical data. *biometrics*, 159–174.

Lasi, H., Fettke, P., Kemper, H.-G., Feld, T., & Hoffmann, M. (2014). Industry 4.0. *Business & information systems engineering, 6(4),* 239–242.

Lavalle, S. (2019). Virtual reality. *Cambridge University Press.*

Lopes, P., You, S., Ion, A., & Baudisch, P. (2018). Adding force feedback to mixed reality experiences and games using electrical muscle stimulation. *Proceedings of the 2018 chi conference on human factors in computing systems* (pp. 1–13).

Lu, Y., Liu, C., Kevin, I., Wang, K., Huang, H., & Xu, X. (2020). Digital twin-driven smart manufacturing: Connotation, reference model, applications and research issues. *Robotics and Computer-Integrated Manufacturing, 61*, 101837.

Malterud, K., Siersma, V. D., & Guassora, A. D. (2016). Sample size in qualitative 65 interview studies: Guided by information power. *Qualitative Health Research, 26(13),* 1753–1760. doi: 10.1177/1049732315617444

Meta. (2022). Meta quest pro – edistyksellisimmät virtuaalilasimme | meta store. From https://www.meta.com/fi/quest/quest-pro/ (Accessed: 11 November 2022)

Michaud, L., & Alvarez, J. (2008). Serious games. Advergaming, edugaming, training IDATE *Consulting & Research.*

Microsoft. (2022). Mixed reality: Spatial sound best practices. From https://docs.microsoft.com/en-us/windows/mixed-reality/design/spatial-sound-design (Accessed: 1 September 2022)

Mihelj, M., Novak, D., & Beguš, S. (2014). Virtual reality technology and applications. *Springer Dordrecht.*

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

Miro, (2022). *The Visual Collaboration Platform for Every Team | Miro*. Miro. https://miro.com/ (Accessed: 12 December 2022)

Mitchell, R., Schuster, L., & Jin, H. S. (2020). Gamification and the impact of extrinsic motivation on needs satisfaction: Making work fun? *Journal of Business Research, 106,* 323–330.

Mittal, A., Scholten, L., & Kapelan, Z. (2022). A review of serious games for urban water management decisions: current gaps and future research directions. *Water Research, 215,* 118217. From https://www.sciencedirect.com/science/article/pii/S0043135422001804 doi: https://doi.org/10.1016/j.watres.2022.118217

Myers, B., Hollan, J., Cruz, I., Bryson, S., Bulterman, D., Catarci, T., . . . Ioannidis, Y. (1996). Strategic directions in human-computer interaction. *ACM Computing Surveys (CSUR), 28*(4), 794–809.

Oliver, D. G., Serovich, J. M., & Mason, T. L. (2005, 12). Constraints and Opportunities with Interview Transcription: Towards Reflection in Qualitative Research. *Social Forces, 84(2),* 1273-1289. From https://doi.org/10.1353/sof.2006.0023 doi: 10.1353/sof.2006.0023

Oliver RL (1977) Effect of expectation and disconÀrmation on postexposure product evaluations – an alternative interpretation. *Journal of Applied Psychology 62*(4):480.

Olsson, T. (2012). User expectations and experiences of mobile augmented reality services.

Olsson, T. (2014). Layers of user expectations of future technologies: an early framework. In *CHI'14 Extended Abstracts on Human Factors in Computing Systems,* 1957-1962.

Metso Outotec. (2022). Act advanced process control - Metso Outotec. From https://www.mogroup.com/portfolio/act-advanced-process-control/ (Accessed: 29 November 2022)

Varjo Technologies. (2022). Varjo xr-3 - the industry's highest resolution xr headset | varjo. From https://varjo.com/products/xr-3/ (Accessed: 11 November 2022)

Paavilainen, J., Korhonen, H., Alha, K., Stenros, J., Koskinen, E., & Mayra, F. (2017). The pokèmon go experience: A location-based augmented reality mobile game goes mainstream. *Proceedings of the 2017 chi conference on human factors in computing systems* (pp. 2493–2498). New York, NY, USA: Association for Computing Machinery. From https://doi.org/10.1145/3025453.3025871 doi: 10.1145/3025453.3025871

Papacharalampopoulos, A., Giannoulis, C., Stavropoulos, P., & Mourtzis, D. (2020). A digital twin for automated root-cause search of production alarms based on kpis aggregated from iot. *Applied Sciences, 10(7),* 2377.

Paravizo, E., Chaim, O. C., Braatz, D., Muschard, B., & Rozenfeld, H. (2018). Exploring gamification to support manufacturing education on industry 4.0 as an enabler for innovation and sustainability. *Procedia Manufacturing, 21,* 438-445. From https://www.sciencedirect.com/science/article/pii/S2351978918301811 (15th Global 66

Conference on Sustainable Manufacturing) doi: https://doi.org/10.1016/j.promfg.2018.02.142

Parmenter, D. (2015). Key performance indicators: developing, implementing, and using winning kpis. *John Wiley & Sons*.

Pelling, N. (2011, Aug). The (short) prehistory of "gamification". . . . From https://nanodome.wordpress.com/2011/08/09/the-short-prehistory-of-gamification/

Poland, B. D. (1995). Transcription quality as an aspect of rigor in qualitative research. *Qualitative inquiry, 1*(3), 290–310.

Polvi, J., Taketomi, T., Yamamoto, G., Dey, A., Sandor, C., & Kato, H. (2016). Slidar: A 3d positioning method for slam-based handheld augmented reality. *Computers & Graphics, 55,* 33-43. From https://www.sciencedirect.com/science/article/pii/S0097849315001806 doi: https://doi.org/10.1016/j.cag.2015.10.013

Punch, K. (1998). Introduction to social research: Quantitative and qualitative approaches. *SAGE Publications Ltd.*

Rebenitsch, L., & Owen, C. (2016). Review on cybersickness in applications and visual displays. *Virtual Reality, 20*(2), 105,117.

Regmi, K., Naidoo, J., & Pilkington, P. (2010). Understanding the processes of translation and transliteration in qualitative research. *International Journal of Qualitative Methods, 9*(1), 16–26.

Rogler, L. H. (1999). Methodological sources of cultural insensitivity in mental health research. *American psychologist, 54*(6), 424.

Roto V, Law E, Vermeeren A, & Hoonhout J (eds) (2011) UX white paper. URI: http//allaboutux.org/uxwhitepaper.q

Sailer, M., Hense, J. U., Mayr, S. K., & Mandl, H. (2017). How gamification motivates: An experimental study of the effects of specific game design elements on psychological need satisfaction. *Computers in Human Behavior, 69,* 371-380. From https://www.sciencedirect.com/science/article/pii/S074756321630855X doi: https://doi.org/10.1016/j.chb.2016.12.033

Sánchez-Adame, L. M., Urquiza-Yllescas, J. F., & Mendoza, S. (2020). Measuring anticipated and episodic ux of tasks in social networks. *Applied Sciences, 10*(22), 8199.

Sandelowski, M. (1995). Qualitative analysis: What it is and how to begin. *Research in nursing & health, 18(4),* 371–375.

Sarwar, M., & Soomro, T. R. (2013). Impact of smartphone's on society. *European journal of scientific research, 98*(2), 216–226.

Sodnik, J., Tomazic, S., Grasset, R., Duenser, A., & Billinghurst, M. (2006). Spatial sound localization in an augmented reality environment. *Proceedings of the*

18th australia conference on computer-human interaction: design: activities, artefacts and environments (pp. 117).

Squires, A. (2009). Methodological challenges in cross-language qualitative research: A research review. *International Journal of Nursing Studies, 46*(2), 277-287. From https://www.sciencedirect.com/science/article/pii/S0020748908002101 doi: https://doi.org/10.1016/j.ijnurstu.2008.08.006

Stachniss, C., Leonard, J. J., & Thrun, S. (2016). Simultaneous localization and mapping. *Springer handbook of robotics* (pp. 1153–1176). Springer.

Stone, S., Jarrett, C., Woodroffe, M., & Minocha, S. (2005). User interface design and evaluation. *Morgan Kaufmann*.

Susi, T., Johannesson, M., & Backlund, P. (2007). Serious games: An overview. *IKI Technical Reports.*

Sutherland, I. E. (1968). A head-mounted three dimensional display. Proceedings of the December 9-11, 1968, fall joint computer conference, part (pp. 757–764). *ACM*.

Swan, J. E., Jones, A., Kolstad, E., Livingston, M. A., & Smallman, H. S. (2007). Egocentric depth judgments in optical, see-through augmented reality. *IEEE transactions on visualization and computer graphics, 13(3),* 429-442.

Tao, F., Cheng, J., Qi, Q., Zhang, M., Zhang, H., & Sui, F. (2018). Digital twin-driven product design, manufacturing and service with big data. *The International Journal of Advanced Manufacturing Technology, 94*(9), 3563–3576.

Tao, F., Zhang, H., Liu, A., & Nee, A. Y. C. (2019). Digital twin in industry: State-of-the-art*. IEEE Transactions on Industrial Informatics, 15*(4), 2405-2415. doi: 10.1109/TII.2018.2873186

Temple, B., & Young, A. (2004). Qualitative research and translation dilemmas. Qualitative research, 4(2), 161–178.
Tilley, S. A. (2003). “challenging” research practices: Turning a critical lens on the work of transcription. *Qualitative inquiry, 9*(5), 750–773.

Trimble. (2022). Trimble xr10 with hololens 2. From https://fieldtech.trimble.com/en/product/trimble-xr10-with-hololens-2 (Accessed: 11 November 2022)

Von Hippel, E. (1986). Lead users: a source of novel product concepts. *Management science, 32*(7), 791–805.

Wright P, Wallace J, McCarthy J (2008) Aesthetics and experience-centered design. *Transactions on Computer Human Interaction 15*(4): article 18, 21p.

Weller, S. C., Vickers, B., Bernard, H. R., Blackburn, A. M., Borgatti, S., Gravlee, C. C., & Johnson, J. C. (2018). Open-ended interview questions and saturation. *PloS one, 13*(6), e0198606.

Williams, C., et al. (2007). Research methods. *Journal of Business & Economics Research (JBER), 5*(3).

Yogasara, T. (2014). Anticipated user experience in the early stages of product development. *Queensland University of Technology.*

Yogasara, T., Popovic, V., Kraal, B., & Chamorro-Koc, M. (2011). General characteristics of anticipated user experience (aux) with interactive products. *Diversity and unity: Proceedings of iasdr2011, the 4th world conference on design research* (pp. 1–11).

Yovcheva, Z., Buhalis, D., & Gatzidis, C. (2012). Smartphone augmented reality applications for tourism. *E-review of tourism research (ertr), 10*(2), 63–66.

Zhang, J., & Singh, S. (2014). Loam: Lidar odometry and mapping in real-time. *Robotics: Science and systems* (part 2, pp. 1–9).

Appendix A. Transcript conventions

Note	Explanation
,	Barely noticeable pause
(.)	Noticeable pause, under 0.2 seconds
(0.0)	Noticeable pause, in tenths of seconds
-	A glottal stop or a cut off
:	Colons indicate a stretched sound
..	Fading of preceding sound or letter
...	Quote is divided or shortened
!	Positive tone or rise in intonation
?	Rhetoric- or straight question
(( ))	Interviewer comments or descriptions
hhh	Speaker breathes out
heh	Speaker laughs
:)	Mutual laughter