

Satu Rantakokko

**Affordance-
based approach
to identifying
and analysing
the possibilities
and challenges of
extended reality
(XR) as a medium
for technical
instructions**



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Tiivistelmä

Tämän tutkimuksen tarkoituksena on tarkastella laajennetun todellisuuden vaikutuksia, kun sitä käytetään teknisten ohjeiden välittämisessä. Tutkimuksessa perehdytään toimivien teknisten ohjeiden ominaisuuksiin ja siihen, mitä mahdollisuuksia ja haasteita laajennettu todellisuus tuo teknisten ohjeiden suunnitteluprosessiin.

Uudet teknologiat tuovat uusia mahdollisuuksia viestintään ja muuttavat tapoja, joilla teknisiä ohjeita voidaan välittää. Aiempi laajennettua todellisuutta käsittelevä tutkimustieto keskittyy pääasiassa yksittäisiin laajennetun todellisuuden muotoihin yksittäisissä työtehtävissä, eikä tietoa laajemmasta näkökulmasta ole vielä juurikaan saatavilla. Teknisen viestinnän ammattilaiset kokevat tarvitsevänsä lisää ymmärrystä siitä, mitä laajennetun todellisuuden käyttö alalla tarkoittaa.

Tämä tutkimus vastaa haasteeseen tarkastelemalla laajennettua todellisuutta teknisten ohjeiden välittäjänä kokonaisuutena. Tutkimuksessa luodaan malli, jota voidaan käyttää työkaluna laajennettua todellisuutta hyödyntävien teknisten ohjeiden organisoituu suunnitteluun ja testaamiseen. Malli mahdollistaa myös laajennetun todellisuuden eri muotojen vertailun toisiinsa ja tukee näin parhaiden vaihtoehtojen valintaa. Tutkimus sisältää kolme vertaisarvioitua tutkimusartikkelia sekä kaksi vielä vertaisarvioimatonta esseettä.

Ensimmäisessä ja toisessa artikkelissa analysoidaan teknisten ohjeiden ja laajennetun todellisuuden keskeisiä ominaisuuksia tavalla, joka mahdollistaa kolmannessa artikkelissa näiden ominaisuuksien tuomisen yhteen siten, että niiden vaikutuksia toisiinsa voidaan verrata. Näin muodostuu tutkimuksessa kehitettävä teknisten ohjeiden laajennettua todellisuutta hyödyntävien teknisten ohjeiden affordanssimalli, TIER. Neljännessä ja viidennessä artikkelissa mallia testataan kokeellisilla tutkimuksilla, joiden perusteella malli vaikuttaa toimivalta ja kykenevältä täyttämään tarkoituksensa.

Asiasanat: Tekniset ohjeet, affordanssit, laajennettua todellisuutta hyödyntävien teknisten ohjeiden affordanssimalli, TIER-malli, laajennettu todellisuus, yhdistetty todellisuus, virtuaalitodellisuus, lisätty todellisuus, lisätty virtuaalisuus, yksityisyys ja turvallisuus, laajennetun todellisuuden terminologia

Abstract

The purpose of this study is to examine the effects of extended reality (XR) when used to mediate technical instructions. The research examines the characteristics of well-functioning technical instructions, as well as the possibilities and challenges brought by XR to the process of designing technical instructions.

New technologies bring new possibilities to communication and change the ways in which technical instructions can be conveyed. Previous research of XR mainly focuses on a certain type of XR in a task, and there is little research adopting a broad perspective so far. Previous research has uncovered that technical communication professionals have identified the need to increase understanding on what the use of XR means in their field.

This study addresses the challenge by taking a holistic view of XR as a mediator of technical instructions. A model is created to be used as a tool for organized design and testing of XR-based technical instructions. The model also enables the comparison of different forms of XR with each other to support the selection of the best options. The research includes three peer-reviewed research articles and two essays.

The first and second articles analyse the key features of technical instructions and XR in a way that enables the third article to bring those features together to facilitate a comparison of effects with each other. The process led to constructing the affordance model of technical instructions in extended reality, TIER. The model is pilot tested with experimental studies reported in the fourth and fifth articles. The tests indicate that the model is functional and fulfils its purpose.

Keywords: Technical instructions, affordance, the affordance model of technical instructions in extended reality, TIER model, extended reality, mixed reality, virtual reality, augmented reality, augmented virtuality, privacy and security, terminology of XR

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The beginning of this doctoral research project occurred back in 2016, when I was trying to figure out the topic for my Masters research. At that time, I became interested in Augmented Reality (AR) and its numerous possibilities, and fell in love with everything that could be done with it. As my field was technical communication, I turned my focus towards the possibilities that AR could offer for technical instructions.

I felt that there was much more research needed, and wanted to continue. When this doctoral research project commenced in August 2018, my research interests soon took a wider approach. From AR, I turned my focus to XR in its entirety, and from benefits to challenges as well. That was a decisive signpost for the whole project, for better or worse. Now, five years later, I am ready to present the journey of this research.

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I have been extremely privileged to have wonderful and inspirational supervisors along the road. These amazing experts have taught me valuable lessons and showed me different ways to do research. As a novice researcher, it is truly valuable to have such an opportunity.

The inspiration for becoming a researcher in the first place was my first supervisor, Anita Nuopponen, who supervised my Masters thesis. Under her wings, I took my first steps. She taught me how to approach the undertaking of research, how to give and receive feedback, and how to be more patient. She tolerated my growth process, but never tolerated errors. I thank Anita also for co-authoring my first article.

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Publications

Rantakokko, S. & Nuopponen, A. (2019). Laajennetun todellisuuden tarjoumat tekniselle viestinnälle - kohti teoreettista mallia. VAKKI Publications, 10, 53-66.

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1 INTRODUCTION

The pace of technological change and its developments seems to be accelerating. Recent examples include the influence of ChatGPT on searching and writing information for researchers and students, robot assistants in tasks such as food delivery and teaching, extended reality (XR) in industry and entertainment, artificial intelligence (AI) for creating artwork, and deep fake videos. New possibilities also bring new risks, such as those to privacy and security. Rapid technological development makes it necessary to ensure there are methods to control and manage differences between more traditional approaches and new features.

The current research has been formulated as a result of the technological changes that influence the work environment and society as a whole. This work acknowledges that research-based frameworks that can assist people in adjusting to changes and knowledge management are needed. The focus of this research is on XR and the consequences of using XR in the field of technical communication. More specifically, this research aims to extend scientific understanding of XR as a medium for technical instructions. This research proposes a method to identify the possibilities and challenges associated with XR in the context of mediating technical instructions, covering all the phases of the design of such instructions. As a result, the affordance model of Technical Instructions in Extended Reality (TIER) is developed, introduced and pilot tested.

In the context of this research, XR is seen as a combination of all realities that include virtual elements as a medium to deliver technical instructions. As such, XR technology can offer context-related, 3D, and interactive instructions that foster new possibilities but also introduce challenges compared to other media. Such possibilities include, for example, enabling phase-by-phase instructions that follow users' actions interactively, guiding them through the complete process of a task. Furthermore, the instructions can be viewed via XR glasses, thus freeing the user's hands for the task. Challenges include delays, possible eye fatigue, and privacy and security challenges owing to the constant recording of the users and their environment.

Because of these possibilities and challenges, and the current limited amount of research and applications, research on this topic is warranted to increase the knowledge of new technologies.

1.1 Positioning the study and research context

This research is based on a combination of two different topics: technical instructions as part of the field of technical communication and XR as an emerging technology. Interest in research on the use of XR in the service of technical communication, and especially in industry, has been increasing recently. Approaches adopted in previous research have typically focused on a specific category of technical instructions and XR rather than considering the two domains as a complete whole. These approaches tend to focus on practical applications and their usability testing from a technology viewpoint (e.g., Dey et al., 2018; Nebeling et al., 2018; Heinonen, 2023). Such specific categories have included how to assist a construction task using an augmented reality (AR) application and how the results compare to other types of instructions (e.g., Tzimas et al. 2019; Doshi et al. 2017; Zauner et al. 2003; Hoedt et al. 2017).

This research aims to fill a gap observed in technical communication research arising from it traditionally overlooking the similarities between technical instructions and XR design. This is conducted by identifying the core of both technical instructions and XR and combining their central features in relation to each other in a way that enables identifying the potential of XR as a medium to deliver technical instructions and the associated challenges.

Furthermore, previous research has shown more interest in comparing some types of XR to other media, like video instructions, rather than comparing different types of XR to each other. Buchner, Buntis, and Kerres (2022) conducted a systematic review of 58 studies and identified a need to compare different XR-based solutions with each other (p. 285). In this research, a systematic, scenario-based comparison is conducted in Chapter 5 with the assistance of the TIER model. The process offers an example of how the TIER model can be used in the unique circumstances of the design process of XR-based technical instructions.

The term technical instructions, as used in this research, incorporates all instructions intended to guide and teach a user of a technical device (Markel 2012, p. 3). Likewise, XR is seen as an umbrella concept encompassing all environments that include virtual elements. The holistic approach of this research makes it possible to develop a method and tool to design various forms of technical instructions delivered via one or more existing or future XR-supporting technologies. This method encourages a systematic approach to task-specific technical solution selection. In Figure 1, the facets of this research are illustrated.

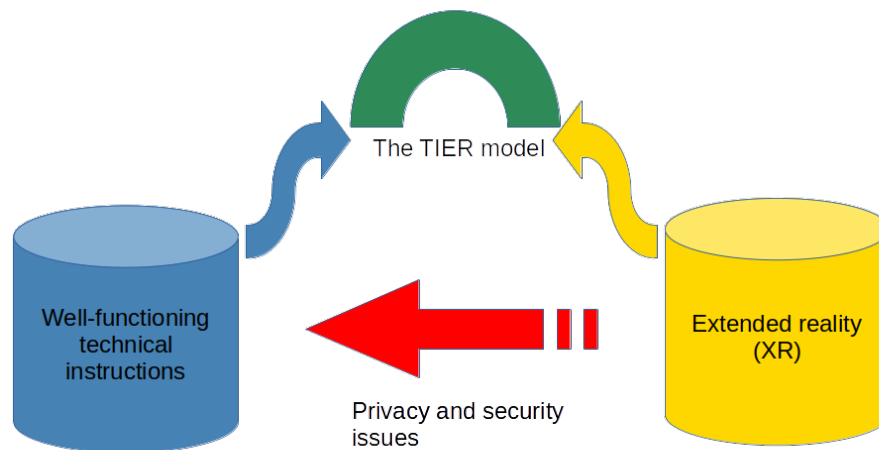


Figure 1. Facets of the current research include technical instructions and extended reality. Extended reality brings along new challenges concerning privacy and security to the context of technical instructions. In this research, these central areas are combined into the TIER model.

This research is situated in the field of technical communication. Therefore, XR's features are seen through the lens at this field's very core. In order to do so, the first step is to identify the structure and the central research topics of the field of technical communication.

1.1.1 Technical communication as a research field

The technical communication field is dual-sided, as it focuses on both theory and practice (e.g., Andersen & Hackos, 2018; Carradini et al., 2020). Amare (2002) reports that the dual nature developed over the history of technical communication. As a profession, technical communication has a long history, while as an academic field, it is remarkably young (p. 538). Despite the dual nature of the field, according to Carradini et al. (2020), "the disciplinary identity of technical communication is well developed" (p. 127). In contrast, Melonçon and Schreiber (2021) argue that this field is dynamic and difficult to delineate and describe (p. 3).

The current research recognizes this dual nature and occupies the middle ground between theory and practice, with a slight emphasis on the theory. In the context of this research, the TIER model is based on scientific theory and is intended for

practical application to design technical instructions. Moreover, the model can also be used for research purposes and is therefore characterized by the dual nature of the field of technical communication.

Duality causes tensions in the field of technical communication but also means that research never forgets practice. There is the opportunity to not only divide the field but build bridges between academia and industry. Amare (2002) examines why resistance to theory is not beneficial for the field and that practice and theory can benefit from each other (p. 538). The same mutual benefit of the research that considers practice is promoted by other researchers, such as Melonçon and Schreiber (2021) and Andersen and Hackos (2018).

The field of technical communication seeks recognition in both the professional expertise of technical communication specialists, and technical communication as an independent research field (see, e.g., Carradini et al., 2020, p. 130). This doctoral research honours both. First, the expertise of technical communication professionals, such as information designers and technical communicators, is recognized. Therefore, this research aims to offer a tool to be used in combination with professional knowledge of technical communication, such as the details of designing technical instructions, requirements of instructions, for example. More information on new technologies, such as XR, is required (Tham et al., 2018, p. 178). This research approaches technical instructions and XR holistically to broaden the knowledge of XR as a medium for technical instructions.

Research topics explored in recent decades clarify what belongs to the field of technical communication and what does not. Based on three recent reviews focusing on central topics in the field of technical communication (Carradini et al., 2020; Turner, 2022; Luo et al., 2022), different approaches to research share aspects related to: 1) teaching, learning, and knowledge sharing; 2) professional practices of technical communicators; 3) research; 4) users; and 5) communicating. The field of technical communication, therefore, includes at least collecting, managing, and transferring knowledge in the focus of research and practice to help users. According to Carradini et al. (2020), focusing on knowledge building and management requires that tools and practices take centre stage in technical communication research (p. 130).

Therefore, this research views collecting, managing, and transferring knowledge from professionals to users as the core of technical communication. The TIER model developed in this research is based on these grounds and is combined with the second topic of interest, XR by applying a grounded theory approach. Technical instructions can be mediated in many forms, including face-to-face, printed manuals, video, and audio (see, e.g., Vanneste et al., 2020, Rantakokko 2022b, p.

25). One recurring challenge is that of understanding how to help the users receive the instructions they need in the right time and in ways they understand, irrespective of what the instructions are about, and who the user is. New technologies, such as XR, may offer novel solutions to meet this challenge.

1.1.2 XR as a novel technical communication medium

In this research, XR is seen as an umbrella concept for different types of realities that include solely virtual elements (virtual reality, VR) or mix them with actual reality (mixed reality, MR). These realities also include human-machine interactions (Fast-Berglund, Gong & Li 2018, p. 32). XR brings both benefits and challenges to the everyday work of professionals involved in technical communication. The potential benefits include being able to provide interactive, context-related, and three-dimensional instructions at all times and combine multiple elements such as text, pictures, and videos related to the real work environment (see, e.g., Piumsomboon et al., 2017, p. 36; Reilly et al., 2014, p. 275; De Guzman, Thilakarathna, & Seneviratne, 2019, pp. 8, 13). That potential improves the chances of the user receiving vital information when needed. In addition, when instructions are available in XR form during the task, there is no need to interrupt the task to read the instructions.

One drawback is that XR requires certain equipment. Currently, this typically involves an XR headset or a smart phone as a minimum requirement. Another challenge is that the nature of XR involves constant data collection of user-based information and the user's environment. This data includes, for example, the user's position and orientation, eye gaze stream, and all the objects around the user. This creates new kinds of cybersecurity, privacy, and ethical challenges. To date, those challenges have not been significant in the context of technical instructions because instructions do not usually include sensitive data. However, towards this direction we find discussions about tactical technical communication, which focuses on how something is actually done, instead of how it should be done (see, e.g., Kimball, 2017).

In the case of XR, it is difficult if not impossible, to avoid collecting, storing, and transferring sensitive data. This data is thus vulnerable to attack. However, according to systematic literature searches conducted in August 2021, studies focusing on privacy and security challenges concerning XR-related technical instructions were almost non-existent. These searches were carried out with different combinations of search words, such as "privacy," "security," "augmented reality," "virtual reality," "technical instructions," etc. Of the resulting 969 papers found in such searches, 28 were selected after preliminary inspection to more

thorough examination. None of them actually focused on the subject directly. They only sided the topic. Accordingly, there are important research gaps to be addressed.

As an assemblage of these topics of interest, this research suggests a conceptual model combining the characteristics that the designer of technical instructions should include in the development of instructions and their features within XR, in order to support the main goals of application and usage. This model is based on the affordances of technical instructions and the central features of XR. It focuses on XR as a whole and concentrates on common features of the technology. There is the added capability of comparing different types of XR embedded within the model. The model takes a broad view of affordances, seeing them from four different viewpoints: rules, design, possibilities, and actualizing (Rantakokko & Nuopponen, 2019). This approach renders it possible to use the model as a tool during the whole design process of XR-based technical instructions. There seems to be a lack of previous models designed to combine the central features of both technical instructions and XR as a whole to offer a tool for analysing, designing, and testing XR-based technical instructions. The TIER model offers an organized method for designing different types of XR-based instructions, thus enabling consistency, predictability and comparability.

Other types of models have been developed however, focusing on different viewpoints, such as the Components of User Experience (CUE) model by Minge and Thüring (2018). CUE aims to integrate analytic theories in order to develop a comprehensive framework for empirical studies. The goal of this model is to assist in finding “an appropriate set of dependent variables and measurements” (ibid., p. 13) in user experience (UX). In comparison, the TIER model focuses on the design process of XR-based technical instructions with the UX just as one viewpoint related to the testing process of those instructions. Recently, Lehtikko, Ruokamo and Nykänen (2022) developed a model for VR in teaching and learning. Their focus was on safety training. Like the TIER model, they are interested in the user’s evaluations. However, while their model focuses on the use of VR in the context of pedagogy, the TIER model focuses on the design of technical instructions for XR in its entirety (accounting for the various modalities of VR, AR etc.). Next, the purpose of this research and research questions are introduced in detail.

1.2 Purpose of the research and research questions

This research aims to provide a method to identify the possibilities and challenges associated with XR in the context of mediating technical instructions. This aim was

approached via three research questions. Each of these research questions is further specified via sub-questions introduced in the articles related to this research. The research questions are:

(1) What are the features of well-functioning technical instructions when delivered via XR?

Article 1 aims to define the main features of well-functioning technical instructions.

(2) How can the benefits and challenges that the use of extended reality brings to the context of technical instructions be identified and analysed?

Article 2 aims to increase knowledge of XR by analysing how data are handled in XR when delivering technical instructions.

Article 3 combines the central features of technical instructions and XR into the TIER model, thus suggesting a method to identify and analyse the benefits and challenges of XR as a medium for delivering technical instructions.

(3) How can the TIER model be used in the testing process of XR-based technical instructions to identify preconceptions and/or for error handling?

Article 4 pilot-tested the TIER model. Simultaneously, it focused on how user preconceptions about new technology can be identified through applying an organized and comparable method, the TIER model.

Article 5 reported the rest of the pilot-testing, while it focused on how technology-based user behaviour can inform the design of XR-based technical instructions.

Together articles 4 and 5 introduce ways to use the TIER model in the design process of XR-based technical instructions. The research process was divided into three phases according to these core questions (see in Figure 2).

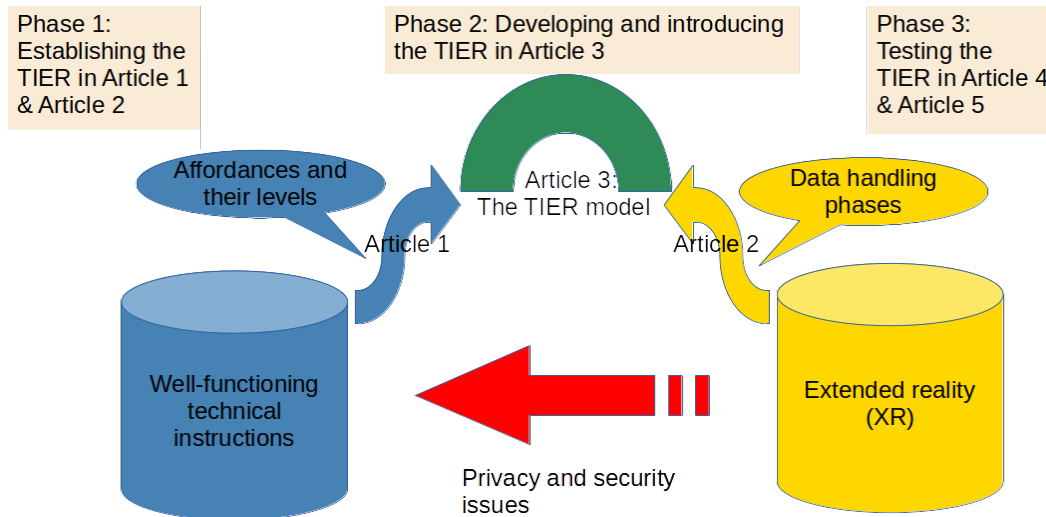


Figure 2. This research was conducted in three phases. Phase 1: the central features of well-functioning technical instructions and the data handling phases of extended reality were defined. Phase 2: The TIER model was developed and introduced. Phase 3: The TIER model was pilot tested.

The first phase of this research established the TIER model. Articles 1 (Rantakokko & Nuopponen, 2019) and 2 (Rantakokko, 2022a) created the base of the research, enabling the formation of the TIER model. Research question 1 represents the aim of Article 1. Article 1 commenced the definition of well-functioning technical instructions, their aims, and main features. The concept of affordance was chosen as the starting point for the research. The initial process also involved developing a conceptual model introducing a new perspective to earlier approaches. The central features of well-functioning technical instructions were identified with the method of analysing and thematizing laws, regulations, and guidance for good technical instructions. This resulted in identifying four affordances of technical instructions. These affordances were accessing, finding, understanding, and relying on.

The concept of affordance was also refined and contextualized in the first research phase. As a result, in this research, each of the affordances is analysed on four levels: rules, design, possibilities, and actualizing. The first phase of this research, covered in Article 1, focused on the level of rules. This is because the sources of this phase included the rules that define the technical instructions, when and how they must be delivered, and what they need to include, among other things. The work

of identifying the affordances and their levels is introduced in Article 1 (Rantakokko & Nuopponen, 2019).

The aim of Article 2 was to map the common features of XR. To move forward towards answering the second question, it was necessary to understand XR as a whole and in a way that enables the comparison of its features with the affordances of well-functioning technical instructions. While analysing earlier research that focused on different types of XR and how it had been used, the significance of the process-based view of XR emerged. Consequently, the six phases of XR data handling when delivering technical instructions were identified. These phases were collection, processing, storage, transfer, combining, and presentation. This data handling process is introduced in the second article (Rantakokko, 2022a).

The second phase of the research process developed and presented the model. Research question 2 also represents the central aim of this research, which is covering a method to identify the possibilities and challenges associated with XR in the context of mediating technical instructions. Once the central features of well-functioning technical instructions and the features of XR that affect the affordances of technical instructions were identified, these two sets of features were combined into the TIER model.

The TIER model supports the organized analysis of the possibilities and challenges that XR brings to the process of designing technical instructions. The TIER model is introduced in Article 3 (Rantakokko, 2022b). This phase of the research represents the level of design in the TIER model and is focused on the design process of XR-based technical instructions, including how the design should be organized and how the right type of types of XR should be chosen to support the desired features of technical instructions. The solution found in the article addresses the aim of this research and specifically research question 2, by offering a theoretical model to analyse the possibilities and challenges fostered by XR when it mediates technical instructions. That step necessitates a pilot test of the TIER model during development to observe preliminary effectiveness indicators.

Therefore, this doctoral research included *Phase 3*, testing and applying the model. The third research question of this dissertation is approached in Articles 4 (Rantakokko, forthcoming) and 5 (Rantakokko & Rousi, forthcoming). The aim of Article 4 was to pilot test the TIER model by using it to analyse the testing process of XR-based technical instructions. Article 4 focuses on user preconceptions by mapping them before and after using XR-based technical instructions to conduct a LEGO construction task. Article 5 (Rantakokko & Rousi, forthcoming) reports two experiments conducted via an XR equipment. The aim was to observe which designed-in affordances the users would notice and how they would act upon

them. Furthermore, of interest was how the behaviour of users could inform the design of XR-based technical instructions. Together, these two articles introduce a pilot-test of the TIER model and present examples of how it can be applied.

Phase 3 of the research focused on the role of end-users in the design process of XR-based technical instructions. When the instructions are designed to meet the needs of the targeted user group, all the desired features are considered. The model facilitates the choice of optimal media to deliver the instructions. This has been created with the intention that the media is chosen at the appropriate stage of development and/or implementation. In this research phase, the users are involved via experimental tests to reveal what happens when they start utilizing the designed instructions. This research phase represents the levels of possibilities and actualizing of the TIER model because it focuses on both the affordances that are noticed by the users when they focus on the instructions (possibilities), and what affordances they accept when they apply the instructions to complete the task (actualizing).

1.3 Dissertation structure

The structure of this thesis is as follows. The introduction (Chapter 1) is followed by a literature review encompassing the central concepts of this research and their definitions: technical instructions; the affordance lens; the taxonomy of XR and a suggested new version of the reality–virtuality continuum; as well as privacy and security concerns. Finally, the TIER model is introduced. Chapter 3 starts by describing the research process and methods used. After that, the research articles are introduced in detail. At the end of Chapter 3, some ethical considerations are discussed. Chapter 4 summarizes the articles related to this PhD research. Chapter 5 focuses on a scenario-based approach to compare different types of XR and their specific features with three different use cases. Furthermore, the amount of privacy and security risk of different types of XR is evaluated. Finally, Chapter 6 includes a discussion of the findings of this research, its limitations, future research ideas, and conclusions.

2 FRAMEWORK OF THIS RESEARCH – DEFINING THE CORE CONCEPTS

The foundation of the research consists of *the features of well-functioning technical instructions* and *the central features of XR*. This chapter first focuses on well-functioning technical instructions. Because technical instructions are seen through the lens of affordances, the concept of *affordance* and examples of how it has been used in previous research will be given. The second main concept of this research, XR, is introduced as a part of Industry 4.0 (Fourth Industrial Revolution, earlier known as Industrie 4.0). A taxonomy of types of XR is presented, and a new version of the reality-virtuality continuum is suggested. Finally, since XR brings *issues of privacy and security* as a new element in the field of technical communication, the focus will be on the discussion of privacy and security issues concerning XR and regarding XR-based technical instructions. The research framework is illustrated in Figure 3.

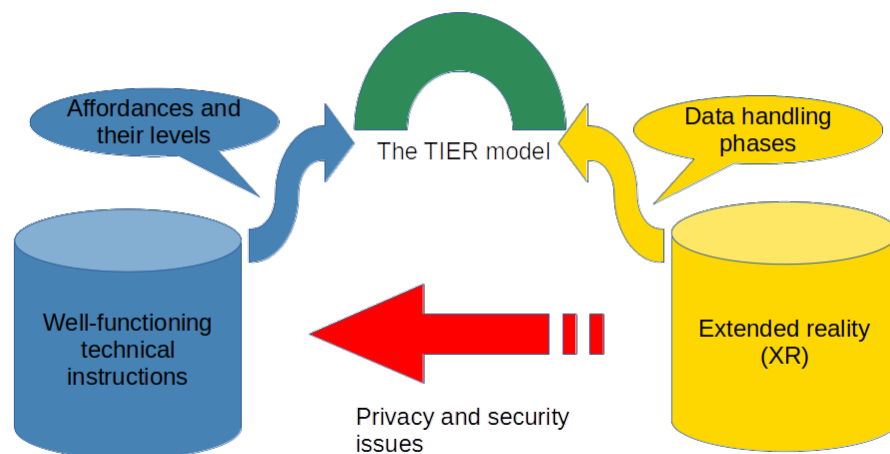


Figure 3. Research framework includes data handling phases of extended reality combined with affordances of technical instructions, and the levels of affordances. Privacy and security issues are notified during the research. The TIER model includes all this.

Figure 3 illustrates the relations between the core concepts of this research. The figure reveals how the TIER model combines the idea of well-functioning technical instructions and XR using an affordance lens on the features of technical instructions and a process-based approach in XR. No uniform definition of any of the central concepts of this research exists. Therefore, it is important to explain in detail how they are seen in this research.

2.1 Well-functioning technical instructions

This doctoral research aims to increase understanding of XR as a medium for technical instructions. The first basic element of the research is the technical instructions themselves. In the context of this research, the term *well-functioning technical instructions* refers to technical instructions that include all the necessary features required for the instructions to fulfil their purpose. Well-functioning technical instructions successfully guide their users on how to operate technical devices (Markel 2012, p. 3). This includes all the phases, from learning how to use the devices to the instructions on recycling them.

2.1.1 Views for technical instructions

Technical instructions, which may be either part of internal or external organizational communication (see, e.g., Baker, 2007), can be delivered in multiple ways, such as face-to-face instructions, printed manuals, video instructions, or XR applications. While more technological devices are used, and communication technologies are changing, there is a growing need for service and research work that employs collaboration and teamwork across different functional work groups (ibid., p. 1). Using many different types of applications may feel frustrating, which increases the emotional burden in the process. Furthermore, the demand for attention and the workload increases, and predictability diminishes. Therefore, more cognitive resources are needed (e.g., Wickens, 2002). Linear work processes and similar methods increase predictability and consistency. Therefore, research concerning knowledge and managing it is one of the central topics in the field of technical communication (Carradini et al., 2020, p. 131). The TIER model offers a tool to manage knowledge transfer as it exists in the form of a method to support designing XR-based technical instructions.

Technical instructions vary by nature. The scope extends from consumer product manuals to detailed instructions for heavy industrial machines for professionals. In addition, there are different requirements for technical instructions, depending on which devices and contexts the instructions are designed for. Despite the broad scope, or rather because of it, this research focuses on common features of well-functioning XR-based technical instructions, rather than use purpose-based differences. While doing so, it addresses a gap in earlier research, which has focused on differences between instruction types rather than shared features.

Previous research highlights many differences between types of technical instructions. Those differences include: 1) variations of media delivering

instructions (see, e.g., Buchner et al., 2022; Chu et al, 2020; Vanneste et al., 2020); 2) differences based on diversity among users, for example, consumers of everyday products such as coffee machines in contrast to professional and specialized users of industrial heavy machines (see, e.g., Vanneste et al., 2020; Loorbach, Steehouder & Taal, 2006); and 3) diverse information needs, such as teaching technical communication or sharing knowledge about technical device use (see, e.g., Taylor, 2006; Carradini et al., 2020).

The exposed differences between types of technical instructions could be argued to be so fundamental as to make it impossible to analyse all technical instructions with the same method or even in the same research. However, even broader aspects have been studied. For example, Budinski (2001) found common features in technical writing (for example, being objective-oriented, communicating issues in engineering and the sciences, and requiring facts or data), of which technical instructions are just one part (p. 15). Budinski situates technical instructions on the spectrum of technical writing by drawing four categories: 1) reports and communications in day-to-day business (e.g., letters, emails, status reports, marketing, etc.); 2) technical papers, magazine articles, books, and theses for purposes of education, teaching, as well as sharing information and knowledge; 3) patents; and 4) operational manuals, instructions, procedures, and process or machine descriptions (ibid, pp. 1-2). The fourth category of these, according to Budinski, is the domain of expertise for technical writers (ibid, p. 2). Budinski's research shows that focusing on common features instead of differences enables the combined analysis of large concepts. In this research, technical instructions are treated holistically.

2.1.2 Well-functioning technical instructions in the context of this research

One of the central tenets of this research is that the common features of well-functioning technical instructions in XR can be analysed by examining affordances. This idea was initially developed in the first phase of this research and published in Article 1 (Rantakokko & Nuopponen, 2019). Article 1 represents the first steps of this doctoral research and illustrates how the thinking behind this research has developed. Although the article was published some time ago, it is included in this dissertation to demonstrate the development of thought and process concerning the TIER model and the understanding of this subject area. The sources used in the article were fresh when writing, but time has passed, necessitating the update provided below that reflects on the ideas of the original article and complements them more recent research.

The main result of the article is that there are four main affordances of technical instructions: accessing, finding, understanding, and relying on. These affordances were identified with a thematic analysis based on relevant literature. The concept of affordance is defined in the next sub-Chapter (2.2). Briefly, it stands for the possible functionalities of an object, either designed or unintended. Next, the four affordances of well-functioning technical instructions will be discussed.

The first common feature of well-functioning technical instructions is the *affordance of accessing*. No matter what type of instructions, in order for them to fulfil their purpose, they need to be accessed by the user who requires them. Transferring information from professionals to those who require it is one of the core topics in the field of technical communication (Carradini et al., 2020, pp. 126, 131). Successful transfer of knowledge requires that the users can access the information. Accessing technical instructions is also related to including all relevant information in the instructions (e.g., laws and regulations, company and industry standards, ethical principles) that create requirements for product documentation to demonstrate awareness of, for example, cultural variables and diverse user needs (e.g., disabilities) (see, e.g., Lipus, 2006; Helyar, 1992).

Accessing became extremely relevant when COVID-19 triggered a requirement for prompt isolation. For many people, the work environment rapidly changed from the office to a remote location. One of the side effects was an enhanced need to manage communication with online-based methods (e.g., Makamara & Adolph, 2022). The requirement created challenges since the infrastructure of many work and home environments was not designed to support remote work, let alone the instructions that would be needed to perform remote work tasks. Challenges included, for example, issues with internet connections, minimal teaching support, and unsuitable home environments (see, e.g., Khan et al., 2021; Almeida et al., 2020).

Accessing is a highly relevant property of new technology in particular. The COVID-19 pandemic spurred strong growth in XR use (Makamara & Adolph, 2022, p. 1). However, high-quality XR equipment is still relatively expensive, which slows down its widespread use. For example, on May 23rd, 2023, a Varjo XR3 cost EUR 6495 in the Varjo online shop, and a Microsoft HoloLens 2 for consumer use cost EUR 3899 (the industrial edition was EUR 5129) in the Microsoft online shop. Therefore, access to XR-based technical instructions may be limited, especially for consumers and work environments, because of the lack of high-quality equipment. Furthermore, standards have only just begun to be fixed (e.g., Makamara & Adolph, 2022).

Accessing can be guaranteed in several ways depending on the possible use contexts and environments, the type of technical device in question, and the special requirements for its use. For instance, if technical instructions are for a consumer product, such as a coffee maker, brief paper instructions may be easiest to access when they are delivered with the coffee maker. Online instructions can then be made available to cover cases in which printed manuals have been lost. Moreover, some devices might demand safety instructions at short notice. Critical time is wasted when searching for instructions to determine the required action.

Furthermore, paper or video instructions are handy, but they are not contextually aware and cannot give real-time information, such as changes to conditions, alarms, or warnings in certain situations, which is possible with XR-based instructions. Well-designed XR-based technical instructions have beneficial access opportunities since the XR technology enables interactive and context-related information to be instantly offered to the user in suitable situations. The benefits depend on how the information is situated, especially concerning safety warnings and critical information (Albert et al., 2014, p. 9; Burova et al., 2020, p. 2).

The second common feature of well-functioning technical instructions is the *affordance of finding*. Relevant information must be found among other information when it is needed. That demands the instructions have been accessed. Then knowledge management and frameworks supporting organized methods become important. When the instructions are well-organized, the information needed can be easily found among other information (Jones et al., 2005). The ideal way of organizing and presenting information varies based on the medium used. For example, printed manuals and video manuals are fundamentally different. In the tradition of technical communication, there is a strong discipline including multiple forms of guidance and teaching in educational institutions (e.g., Carradini, 2020). However, the newer the medium, the less specified design guidance for technical instructions is available, a situation that causes issues.

Technical communication professionals require knowledge to benefit from the technology when designing context-related, interactive, and 3D XR-based instructions. In the context of finding information, for example, if the instructions are AR-based, the user needs to be able to find both actual and virtual elements. Therefore, actual reality cannot be blocked by virtual elements. Nevertheless, virtual elements must still be situated in the right place at the right time. Another challenge is to situate crucial information in order to draw the user's attention when it is needed, instead of, for example, being located behind the user and remaining unnoticed. According to Aukstakalnis (2017), vision dominates human sensory perception, learning, cognition, and activities and is thus the most

effective way to deliver information (p. 332). Therefore, it is important to design visual elements in a way that they are easy to find when using XR equipment, such as positioning all elements in the same corner that is easily locatable by the user (Burova et al., 2020, p. 5). However, identifying and using visual elements can be assisted with audio or haptic elements, for example (ibid., p. 8).

The third common feature is the *affordance of understanding*. When the instructions have been accessed and the relevant information revealed, it must be understandable and useful. Understanding instructions rests at the very core of technical communication. Markel (2012) states that technical communication focuses on guiding and teaching users about technical devices (p. 3). For this purpose, elements within technical instructions should exist in forms that users can understand; that is, they should be provided in relevant languages or using clear and informative diagrams.

Teaching is a central topic of technical communication (e.g., Carradini et al., 2020; Turner, 2022; Luo et al., 2022). The topic includes not only allowing access to information but also assisting in understanding that information. Cognitive processing is at the centre of learning. Several fields of scholarship are valuable for technical communication from this viewpoint. Those fields include cognitive science, cognitive psychology, and neuroscience in their research on how the brain processes information (e.g., Remley, 2016). A broad knowledge base is needed to design most effectively in terms of understanding and learning.

Tradition and previous experiences play a significant role in both finding and understanding information. Even if traditional modes of instruction are not ideal, they can initially be more functional than newer, more effective methods. The situation is a consequence of prior learning and people being accustomed to finding and understanding information in specific ways. The notion was confirmed in Chu et al.'s (2020) research on instructions for constructing Duogong, a traditional Chinese architectural building. According to the authors, Duogong is so complex that people struggle to understand 2D drawings and printed text instructions. Nevertheless, when offering 3D interactive instructions, the research found no notable improvements in error handling or assembly times. They concluded that this was because users were familiar with the traditional instructions and were accustomed to finding information in the traditional form. Therefore, when starting to use new technology, the best benefits may take time for users to accrue as they learn to receive and use the new modes of instruction.

The fourth affordance is the *affordance of relying on*. In today's media landscape, reliability has gained prominence. The user needs to have enough preliminary reliance on the instructions to start using them in the first place and to keep

returning to the instructions when needed. Furthermore, in reliable instructions, the other three affordances – accessing, finding, and understanding – become actualized for users (Rantakokko, 2022b, p. 32). For XR-based instructions, for example, users must have access to the required equipment and that the equipment is functional, including an online connection if required. Furthermore, it includes the design of XR-based technical instructions is such that the user can find relevant information when needed. For example, that virtual elements are situated where they are supposed to be without causing delays. Finally, this information is understandable when conveyed to users and avoids possibilities for crucial misunderstandings.

With the affordance of relying on, user preconceptions, attitudes, and previous experiences play an important role. In the context of this research, preconceptions are especially viewed as positive or negative opinions formed towards XR before trying it as a medium for technical instructions. Furthermore, preconceptions and expectations prepare users for appropriate behaviour (e.g., Pearson et al., 2006; Tetlock, 1999). Regarding XR-based technical instructions, preconceptions can exist regarding both technology and technical instructions. Therefore, preconceptions must be identified and managed (e.g., Churchill & Churchill, 2005; Clark, 2013).

The four affordances form the core of the TIER model. These affordances are common for all technical instructions. They support the basic goal of technical instructions in assisting users with technical devices. Based on these four affordances identified at the beginning of this doctoral research, technical instructions are viewed holistically in the TIER model. A holistic perspective is needed because focusing on common features of both technical instructions and XR enables an organized design process of XR-based technical instructions, despite the details of specific cases. The holistic perspective thus enables continuity in work environments and comparable methods for designing and testing XR-based technical instructions. While updating the basic ground of the TIER model during this research, the model itself still holds and remains valid. Next, I will introduce the concept of affordances in general and how they are seen in this research.

2.2 Affordance as relationships

This research approaches technical instructions through an affordance lens, meaning that both the desired and unintended features of any designed technical instructions are considered affordances. A central aspect of the concept of

affordance is that of a relationship. An affordance always is related to an object and an actor who realizes what the object can be used for. This perspective is central to the basic understanding of affordances in this research.

2.2.1 Origin of the concept

The concept of affordance comes from James Gibson (1979), who pointed out that animals perceive objects through possible functionalities. For instance, instead of an animal perceiving a puddle of water, it perceives possible functionalities, e.g. affordances. Affordances of a puddle of water could be the possibility to drink, wash, or splash in the water. Similarly, humans can also use objects in different ways. As designed, a chair can be used for sitting on, but it also can be used as a clothes rack, to hit someone with, or as a platform for drawing upon. The intended uses do not have to be reasonable or logical. They are anything that the user deems to be possible to accomplish with the object. These possible functionalities exist regardless of whether the user implements them. This understanding of affordance is therefore mainly based on the relationship between an actor (e.g., an animal or a person) and an object (e.g., a puddle or a chair).

Views on the concept vary and Gibson's ideas have been both praised and criticized. For example, Norman (1999) first criticized Gibson's idea of affordance as a naturally-existing relationship, but gradually began to appreciate the concept despite fundamental differences of opinion (pp. 39–41). Norman focused on so-called display-based products and their design, which strongly influenced his views on affordance. He valued some other concepts, such as cultural practices, over affordances. He divided affordances into *real affordances* that an object enables and *received affordances* that a user sees as possible (ibid., pp. 39-41). In Norman's view, affordances "reflect the possible relationships among actors and objects: they are properties of the world" (ibid., p. 42). The notion of affordance in the form of relationships is introduced in Figure 4 and is presented according to Gibson and Norman's view as a relationship between users and objects.



Figure 4. Affordance in the form of relationships between the users and the objects, according to Gibson and Norman.

Maier (2009) saw that the relationships between actors and objects have a fundamental role in design work, and accordingly largely focused on the definition and closer examination of these relationships (p. 13). He approached the concept

of affordance based on his interest in engineering work with both traditional machines and modern objects. Accordingly, Maier posits that traditional function-based and algorithm-based theories of design cannot meet all the challenges and requirements arising from them, so a different approach is necessary (ibid., p. 13). Maier suggests that in design work, affordance as a relative concept helps to both understand and describe the intertwined and complex relationships between designers, users, and objects (ibid., p. 13).

Maier (2009) argues that the concept of affordance has the following relationships: (1) the designer designs the object; (2) the users use the objects – designers therefore create affordances for objects by defining all the properties, such as dynamic functions and colors, that enable a certain set of applications for certain users – these designed affordances define how the object can be used; and (3) there is also a relationship between designers and users (p. 18). Maier posits that this relationship is based on the interaction between the actors, where users tell and designers receive ideas about what users would like the object to do; that is, what affordances the designer should include in the object (ibid., p. 19). Maier's idea of affordances as relationships is pictured in Figure 5.

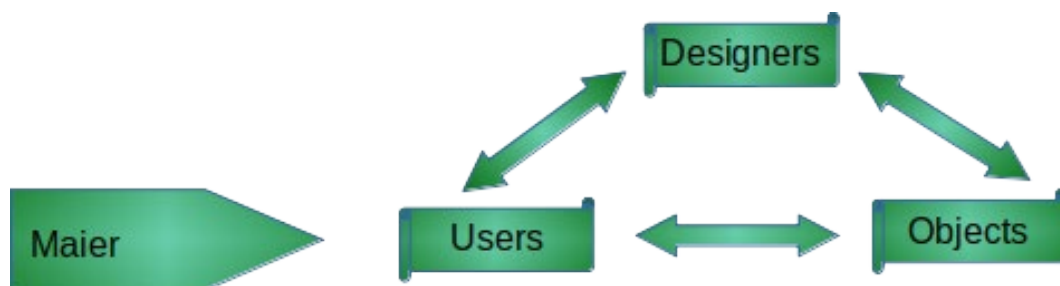


Figure 5. Affordances in the form of relationships between the users, the objects, and the designers, according to Maier.

2.2.2 Synthesis of different views on the concept of affordance

Lanamäki, Thapa, and Stendal (2016, pp. 126–127) viewed affordance broadly from four alternative stances: *canonical affordances*, *designed affordances*, *potential affordances*, and as *completed actions*. Their research thus brings together various concepts of affordance, with a different emphasis and with applications in research and planning work. The study emphasized the importance of defining proportionality and temporality and asked what form the relations between said actors and objects take, and when affordances occur. The study was particularly focused on information systems research.

Canonical affordances are based on the relationship of the object class to socio-cultural practices. For example, the purpose of chairs is to act as seating surfaces. From this point of view, the affordance exists at the level of the concept before designing the object and interacting with it. Lanamäki et al. (2016) therefore make a different division to Norman. For them, (socio)cultural practices are one way of looking at affordances rather than as a separate concept. (ibid., p. 129)

Designed affordances are based on the relationship between the designer, the object, and the user. The subject of examination is the way in which the designers include the affordances they have chosen in the product and how these designed affordances are adapted in use situations. Potential affordances focus on the relationship between the object and the (real or imagined) user, e.g., the functions that the user can perform with the object. The use can also be something other than the purpose for which the object is designed (Lanamäki et al., 2016, pp. 131, 136). This stance is close to Norman's received affordances, that is, what possible functionalities the user sees in the object (ibid., pp. 39–41).

Affordances as completed actions refers to the relationship between the real object and the real user in a certain situation. From this point of view, it is possible to examine how the affordances are manifested in real, situation-related functions (Lanamäki et al., 2016, p. 136). Canonical, designed, and possible affordances do not usually expire. Rather, designed and possible affordances can either be fulfilled or remain unfulfilled. The affordance only ends when the activity is completed (ibid., p. 128). The stances and emphasis on the concept of supply vary depending on the starting point from which the topic is approached. Affordances as relationships, as represented by Lanamäki et al.'s four stances, are illustrated in Figure 6.

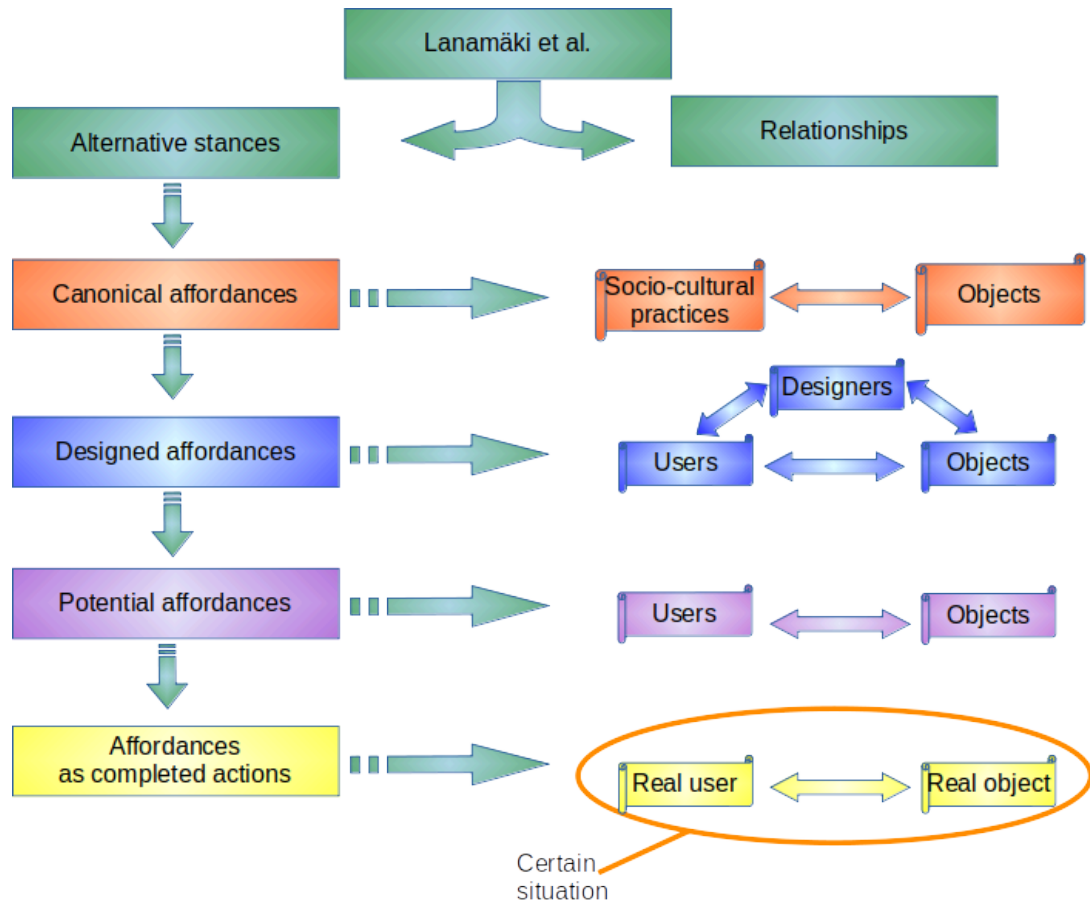


Figure 6. Affordance in the form of relationships as represented by Lanamäki et al. (2016). Affordances can be seen as canonical, designed or potential affordances, or affordances as completed actions. Canonical affordances can be seen as a relationship of objects and socio-cultural practices. Designed affordances are relationships between the users, objects, and designers. Potential affordances are relationships between the users and objects. Affordances as completed actions are relationships with real users and real objects, in a certain situation.

2.2.3 The concept of affordance in this research

This research views the affordance concept broadly, mostly drawing on Lanamäki et al.'s work (2016). The stances from that study are slightly modified to simultaneously valid levels. In previous research, the approach is usually one-dimensional and static (e.g., Treem & Leonardi, 2012; Benbunan-Fich, 2017; Diehl, 2004). Viewing affordances through their levels enables a multidimensional and process-oriented approach, which is functional in a design process. Figure 7

illustrates the relationships of affordances on different levels that are to be found in this research.

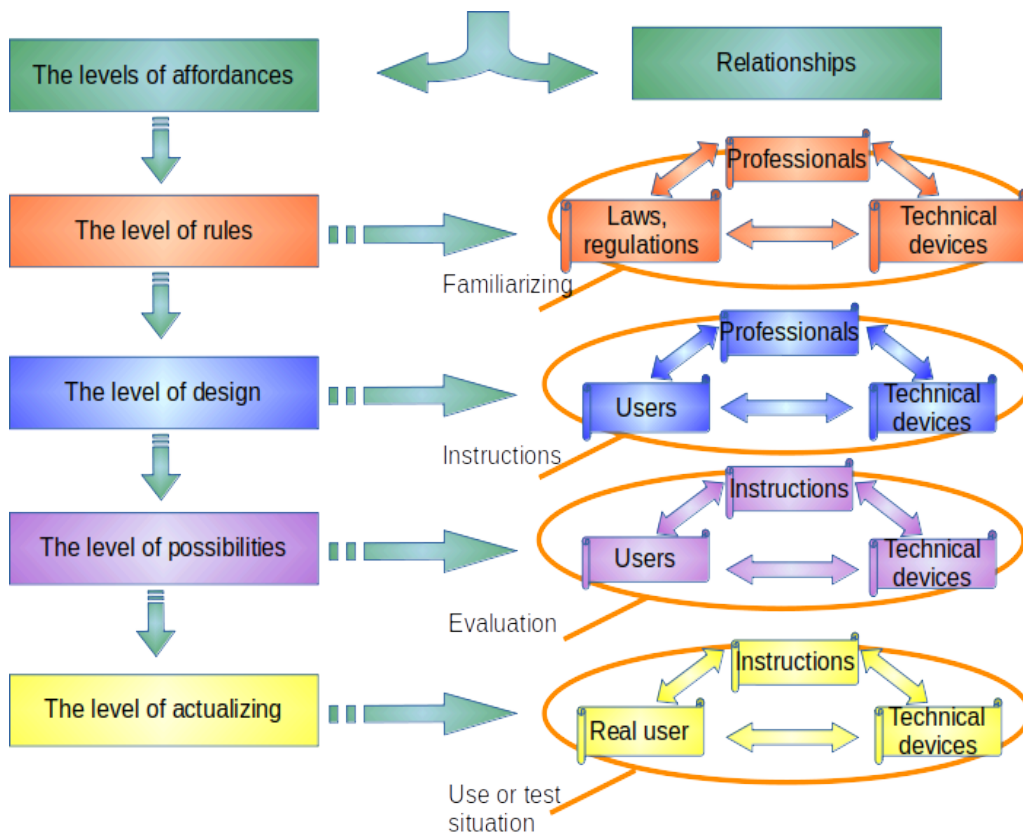


Figure 7. Affordances and their relationships on the levels of the TIER model. The level of rules includes relationships between technical devices, laws and regulations, and professionals of technical communication in the context of familiarizing. The level of design focuses on the relationship of technical devices, the users, and the professionals in the context of the instructions. The level of possibilities targets the relationship of technical devices, the users, and the instructions in the context of evaluation. The level of actualizing focuses on the relationship of the technical devices, the real users, and instructions in a use or test situation.

In the TIER model, the levels have a temporal relationship with each other, thus guiding an organized design process. First, on *the level of rules*, the professionals in technical communication, the technical devices, as well as laws and regulations exist in relation to one another. Technical communication professionals must be familiar both with the technical device and what is required of the instructions related to that particular device. The context varies, depending on whether the

device is, for example, a consumer coffee maker or a heavy industrial machine. Therefore, laws, regulations, and guidance differ by product and thus differ in terms of what is required of the instructions, how and when they should be available for users, and other practicalities.

On *the level of design*, the knowledge of technical communication professionals is combined with the design process of XR-based technical instructions. In the context of the design process, the relationship in a user-centred design is between the users, the professionals, and the technical devices. If the process is not user-centred, the users on this level are a conceptual model of users in the mind of the professionals rather than actual users. Here, communication with real users is not included.

On *the level of possibilities*, the focus turns to the users. The relationship is between the users, the technical devices, and the technical instructions the users receive. On this level, the users do not yet engage with any task but notice a set of affordances that the instructions offer them. Some designed-in affordances may remain unnoticed at this point.

On *the level of actualizing*, the relationships are the same as on the level of possibilities, but the context is engaging with the task in an actual use or test situation. Here, as with mentioned earlier, some affordances may remain unnoticed. The phases of design, opportunities, and actualizing are repeated in an iterative design process until the desired result is achieved through well-functioning technical instructions. Next, the second core concept of this research, XR, is introduced in detail.

2.3 Taxonomy of extended reality (XR)

XR is the second of two core concepts of this research. The TIER model developed in this research includes central features of technical instructions combined with the central features of XR. Here, interest in XR focuses on its possibilities and challenges when it is used to deliver technical instructions. XR is part of the so-called Industry 4.0 notion. According to Herman et al. (2016), the term refers to the fourth industrial revolution and originates in 2011 in an initiative named Industrie 4.0 (p. 3929). The representatives of the initiative engaged in business, politics, and academia. Their interests were in strengthening the German manufacturing industry. Fataliyev and Mehdiyev (2020) stated that the purpose of the concept of Industry 4.0 was to develop “more efficient, safe, environmentally friendly and less costly production, as well as the possibility of single production while maintaining the economic conditions of mass production” (p. 2).

The key enabler of Industry 4.0 is the Internet of Things (IoT) which connects devices online. Another important element is the combination of physical and virtual elements, which is made possible by a cyber-physical system (CPS). A CPS integrates computation and physical processes, which are two key components of Industry 4.0. The third key component is smart factories, which integrate the ideas of the IoT and CPS (Herman et al. 2016, p. 3929). More recently, Fataliyev and Mehdiyev (2020) added that besides IoT and CPS, the key links of Industry 4.0 also include “artificial intelligence (AI), robotics, and other advanced technologies” (p. 2). Mannhardt et al. (2020) also introduced wearable technologies into this context, highlighting the significance of the collected data (p. 201). It is also apt to add the Internet of Bodies (IoB) to the list. El-Khoury (2021) states that IoT is progressing toward IoB, which presents new, complex challenges, such as issues of discrimination and safeguarding privacy and security (p. 307). Depending on the source consulted, other elements can also be included in Industry 4.0.

Herman et al. (2016) defined the design principles of Industry 4.0 in general as: 1) interconnection (including collaboration, standards, and security); 2) information transparency (including data analysis and information provision), decentralized decisions; and 3) technical assistance (including virtual assistance and physical assistance). However, the design principles of Industry 4.0 ignore the perspective of workers, and the issues of privacy and security. This is because human factors are not covered in the paradigm of CPS. (pp. 3932-3933) As stated by Mannhardt (2020), “[t]his raises concerns about threats of the usage of the data, which may be more significant than perceived benefits” (201). The current research highlights the aspect of practitioners and privacy and security issues.

Today, the lexicon of XR is rather unsettled. Some terms are defined in alternate ways. The lack of consensus makes the discussion difficult and creates ambiguity between studies. This dissertation contributes to alleviating the uncertainty by illustrating how the terms have been used. This research views XR as an umbrella concept encompassing all realities that include virtual elements (e.g., Fast-Berglund, Gong, & Li, 2018, p. 32). In other words, XR is an umbrella concept for MR and VR. Alongside that definition, an alternative presents XR as an umbrella concept encompassing only AR and VR (e.g., Rauschnabel, Felix, Hinsch, Shahab & Alt, 2022).

In this research, the definition of XR as an umbrella concept for MR and VR is adopted rather than AR and VR because of the following reasons. First, this definition is drawn from the tradition of earlier research. From the beginning, AR and AV have been seen as parts of MR (e.g., Milgram & Kishino, 1994). Second, when XR refers to only AR and VR, it excludes other types of MR. When using

MR / VR, the simplicity remains without exclusion. Third, it is more accurate since other types of MR are still developed and used. However, there is a challenge since AR is a largely used term. Fourth, based on the number of results in searches with search engines, MR is a considerably more common term than AR. For example, Microsoft and Meta use MR instead of AR in their products and applications.

In the context of this research, the features of XR are derived from Azuma's (1997) characteristics of AR: the combination of real and virtual; real-time interactivity; and three-dimensionality (p. 2). These characteristics are considered suitable for the definition of MR and VR, except for VR being completely virtual instead of a combination of real and virtual.

Next, I will introduce the taxonomy of XR as presented in studies in recent decades and ultimately suggest and justify a new version of the reality–virtuality continuum. Later, in Chapter 5, each type of XR will be compared via brief, general-level example scenarios.

XR, as an umbrella concept, consists of completely artificial virtual reality (VR) and mixed reality (MR), which combines virtual elements with a real environment. MR is most commonly viewed as comprising AR and augmented virtuality (AV), as introduced in Milgram and Kishino's virtuality continuum (1994) shown in Figure 8. However, AR and MR are often confused and used synonymously in everyday language. AV is rarely mentioned, let alone other types of MR. In most cases, it is justified to talk about MR in general without distinguishing its different types. Some types can be classified more in terms of curiosities, rather than serious alternatives with functional applications.

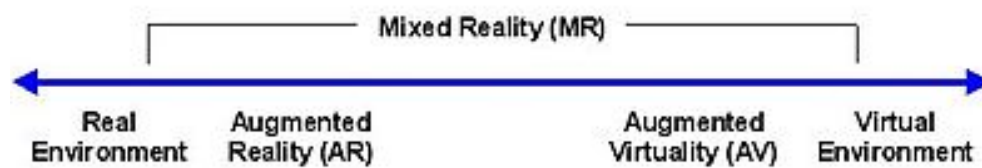


Figure 8. Virtuality continuum by Milgram and Kishino (1994) includes real environment and virtual environment at the ends of the continuum. In the middle there is mixed reality, including augmented reality and augmented virtuality.

Schnabel, Xiangyu, Seichter, and Kvan (2007) developed the continuum further, taking into account more types of MR. In their continuum, “real reality” comes before amplified reality, followed by AR, mediated reality, AV, virtualized reality, and VR, as shown in Figure 9. These types of XR are defined and introduced later in sub-chapters 2.3.1 – 2.3.3. According to Schnabel et al. (2007), “[t]he shared

philosophy behind these concepts is to bring the virtual world of computers into the physical world of everyday human activity” (p. 2). Schnabel et al. also noticed the lack of clarity in identifying and defining these concepts and their attributes. They note that, “[t]his is due to the nature of reality being an inherent concept of existence and derivations are only possible through technological enhancements” (ibid., p. 2).

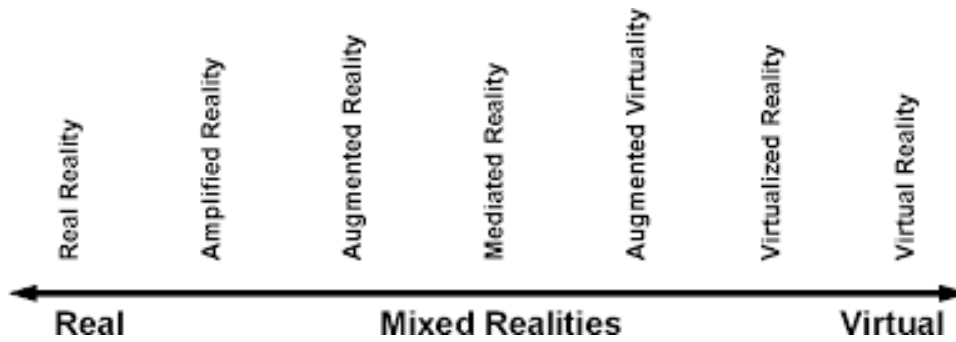


Figure 9. Reality–virtuality continuum by Schnabel et al. (2007, p. 8) divides mixed reality in amplified reality, augmented reality, mediated reality, augmented virtuality, and virtualized reality.

Olsson (2012) added diminished reality between AR and mediated reality on the continuum. Olsson’s dissertation includes a definition of what he termed the reality-related concepts. Olsson’s continuum is introduced in Figure 10.

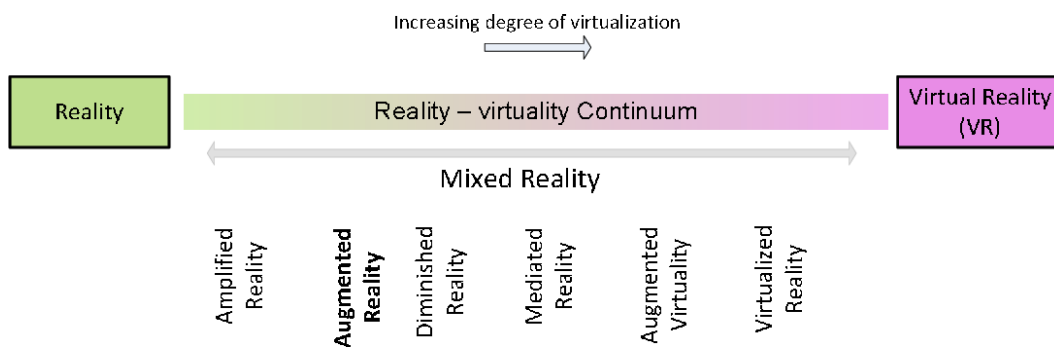


Figure 10. Reality–virtuality continuum by Olsson (2012, p. 33) complements the previous continuums with diminished reality in-between augmented reality and mediated reality.

Olsson asserts that different concepts represent different levels of abstraction (ibid., p. 34). While VR, virtualized reality, and AV are mostly computer-generated, and the placement of all the contents is known, the rest of the types are primarily based on actual reality, and the placement of actual objects is not previously known (ibid., p. 34). The current research suggests a new version of the reality–virtuality continuum, presented in Figure 11.

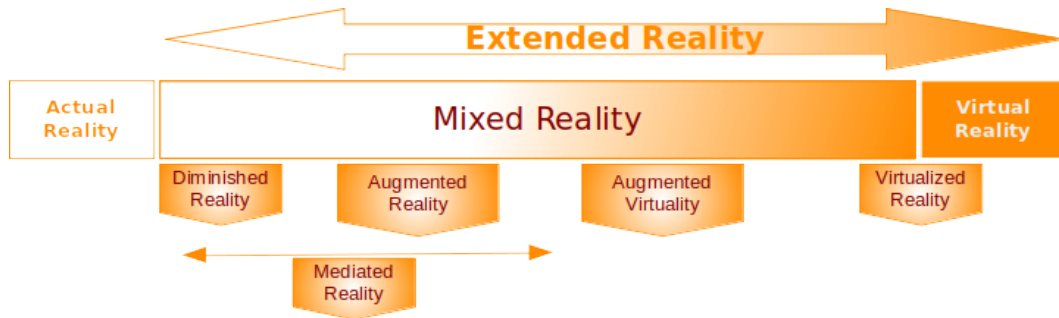


Figure 11. Reality-virtuality continuum suggested in this research adds extended reality as an umbrella concept of mixed reality and virtual reality. It considers re-situating forms of mixed reality, and excludes amplified reality.

The revised version introduced here is justified because the concepts have changed over time. Some types of XR have been applied actively, while some have remained marginal. In recent years, XR has emerged and become established as an umbrella concept for realities that include virtual elements, which warrants its addition. Amplified reality, on the other hand, rapidly faded from popularity shortly after the concept was invented and the three first applications developed. Furthermore, it is debatable as to whether the definition of amplified reality can justifiably be included in XR. Accordingly, it does not feature in the revised continuum. That choice is explained in more detail in sub-Chapter 2.3.3.3. Other types of MR. There are some other minor modifications as well, justified below.

2.3.1 Actual reality

Approaching the concepts of XR requires a brief look at the concept of reality. Since the definition of XR includes virtual elements, actual reality cannot be counted as part of XR. Despite the differences in defining concepts of XR, the exclusion of actual reality is largely accepted (see, e.g., Fast-Berglund et al., 2018; Rauschnabel et al., 2022). Nevertheless, the experience of XR mimics reality, trying to make the users receive a realistic, immersive experience. In the context of this research, all the media to deliver instructions that do not meet the definition of XR (being interactive, 3D, real-time, and including virtual elements) are counted under the umbrella of actual reality. The actual reality is positioned in relation to XR in Figure 12.

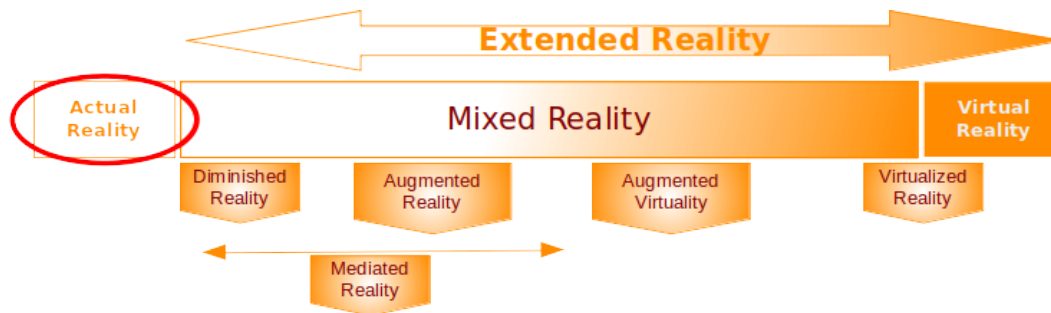


Figure 12. The actual reality on the reality–virtuality continuum is situated in the left end.

Defining what is real has long been debated by philosophers. Descartes, Kant, Hegel, Marx, Locke, Hume, and Chomsky are among those who attempted to delimit the concept of reality (see, e.g., Yolton, 1996). Virtual elements and developing technologies could add new challenges to this debate (see, e.g., Zhai, 1998): if and when all the virtual elements can be sensed just the same as ‘real’ ones (e.g., Papagiannis, 2017), how can we define what is real and separate actual reality from what is virtual, when artificial elements and solutions, like deep fake videos, are getting increasingly realistic?

One solution could be to look at the effects. You can taste virtual elements (see, e.g., Papagiannis, 2017, p. 64), but virtual snacks will not nourish you. You can pat a virtual wall and feel the pressure and the structure (see, e.g., Papagiannis, 2017, pp. 26-27), but it will not keep the wind away. You can enjoy a virtual landscape and mountains far away, but as it is all reflected on the screen close to your eyes, your eyes will get tired.

Niiniluoto (1999) noted that the “word ‘real’ is derived from the Latin ‘res’, which means things both in the concrete and abstract senses” (p. 1). He divides perspectives on reality into six categories: ontology, semantics, epistemology, axiology, methodology, and ethics. For this research, the most valid area is the ontological perspective, which states that a mind-independent reality exists (ibid., p. 21). Especially materialism, as one traditional viewpoint on ontological approach, is functional for this research. Niiniluoto (1999) defined materialism as follows.

According to materialism, everything is composed of, or determined by, matter, where matter as a substance is characterized by its being ‘extended’ (as Descartes said), e.g. located in space and time, and thereby the object of the physical science. While the structure and properties of matter are gradually revealed by physics (atoms, elementary particles, quarks, fields of energy, superstrings, space-time,

etc.), philosophical materialism has emphasized that matter exists ‘outside’ our mind and independently of it. (Ibid., p. 21)

From this point of view, reality is not dependent on sensory perceptions, and virtuality can be separated from reality, even though the aim is that virtual elements can be sensed the same way as the elements of reality, with all senses. Therefore, there is a difference between interacting with our real bodies rather than avatars and interacting with real objects rather than with virtual elements that do not exist in the real environment.

2.3.2 Virtual reality

Virtual reality is at the other end of the reality–virtuality continuum in relation to actual reality. While in actual reality, everything is material, in virtual reality, elements are artificial. According to Mazuryk and Gervautz (1996), the idea of VR was presented by Ivan Sutherland in 1965. The first application was developed by Morton Heilig in 1960–1962 (p. 2). According to Dixon (2006), Jaron Lanier is widely credited with coining the term ‘virtual reality’. Even though this term is one of the most solid ones in XR, there are some differences of opinion. According to Etambakonga (2021), VR is used by many scholars “interchangeably with cyberspace and artificial reality” (p. 3).

In the context of this research, VR represents an environment intended to be completely immersive. The sense of immersion, or the sense of existing and interacting in the virtual environment (e.g., Kronqvist, Jokinen & Rousi, 2016), results from the illusion remaining unbroken. The challenges in creating an unbroken illusion are mainly technological. Zheng et al. (1998) state that immersion involves blocking out distractions to be able to focus on the required information. Interactivity, in turn, means “interaction between humans and events in the virtual world” (p. 20). VR is defined in this research as an environment that is 3D, context-related, and interactive in real-time. It differs from other types of XR in that it is completely virtual, while other types mix actual reality with virtual elements. Figure 13 illustrates how VR is positioned in this research on the reality–virtuality continuum.

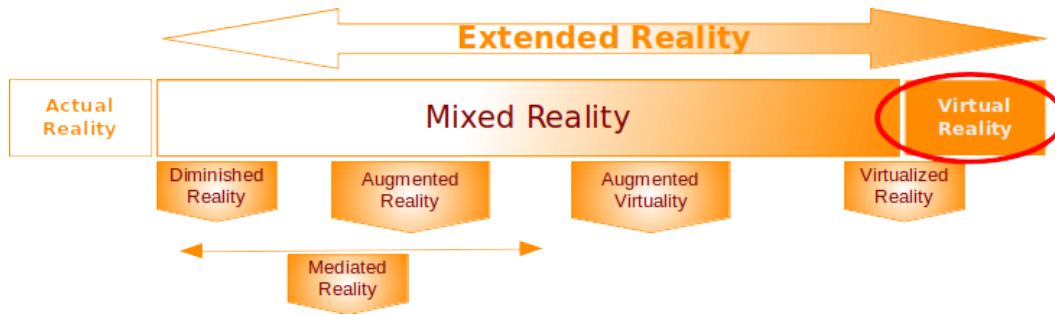


Figure 13. Virtual reality on the reality–virtuality continuum is situated in the right end.

There are other definitions of VR as well, with a different emphasis and more or less characteristics. For example, Etambakonga (2020) lists the following features of virtual reality: the use of certain equipment; being immersive and highly interactive; incorporating a first-person view; being computer-generated and multi-sensory; operating in real-time; and being an information environment (p. 3). Zheng et al. (1998) defined VR as “an advanced, human-computer interface that simulates a realistic environment,” where “the participants can move around in the virtual world. They can see it from different angles, reach into it, grab it and reshape it” (p. 20). Brooks (1999) defined the experience of virtual reality “as any in which the user is effectively immersed in a responsive virtual world. This implies user dynamic control of viewpoint” (p. 16). Mainly, the various definitions are different ways to phrase the same features.

2.3.3 Mixed reality

Between actual reality and VR, there is mixed reality. MR is an umbrella concept for an unspecified number of different realities that mix both real and virtual elements. The term was originally introduced by Milgram and Kishino (1994) who defined MR as the portion between actual and virtual reality, consisting of AR and AV. Later, other types of MR were added to the reality–virtuality continuum.

MR is probably the least stable term within the XR family, as it is often connected to numerous definitions. De Guzman (2020) defines MR through AR and VR viewing it as a combination of aspects from these respective types of XR (pp. 1–2). According to De Guzman, MR allows interaction between real virtual objects and can offer rich services and immersive experiences (ibid., pp. 1–2). Zhao’s (2020) definition of MR states that physical in addition to digital objects and entities can coexist and interact with each other in real time at a higher level (pp. 58–59). Zhao states that the continuum ranges from a completely real and natural to a

completely virtual space, which indicates that in Zhao's definition, also actual reality and VR are included in MR.

This research uses a definition of MR derived from the tradition created in the original reality–virtuality continuum by Milgram and Kishino (1994) and used by many scholars since. Therefore, MR is defined as all the types of realities that mix elements of actual reality with virtual elements in 3D, real time, and in an interactive manner. Therefore, it is positioned between actual reality and VR on the reality–virtuality continuum. The types of MR and how they are situated on the continuum is modified, but the idea of MR remains the same. Figure 14 illustrates how MR is situated on the continuum.

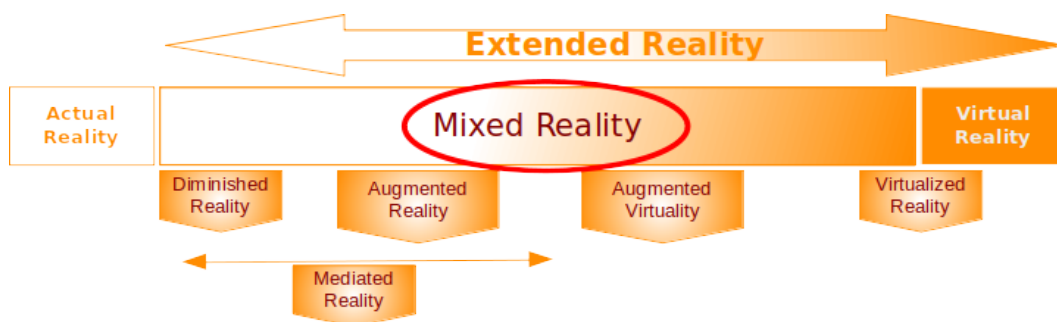


Figure 14. Mixed reality in reality–virtuality continuum remains in-between actual reality and virtual reality.

De Guzman et al. (2020) report many releases of MR applications in recent times (p. 2). These include those of Pokémon Go in 2016 and head-mounted displays such as Microsoft HoloLens (at the time of writing, also HoloLens 2) and the Magic Leap One (Magic Leap 2 was released on September 30, 2022). However, since MR is much more than AR, this raises the question of what types of MR these applications are capable of supporting. Other issues that arises refers to how the manufacturers of these devices define MR, and/or if this is simply a question of terminology, implying that the solutions are actually AR-based. For example, the aforementioned Pokémon Go is a very simple AR application with no elements of other types of MR. In the following chapters, I will first introduce the traditionally acknowledged types of MR: augmented reality and augmented virtuality, and then the other, perhaps more debatable, types of MR.

2.3.3.1 Augmented reality

The history of AR is long, and as with VR, it is difficult to determine who was its inventor. According to Arth et al. (2015), Ivan Sutherland created the first AR system in 1968, also seen as the first VR system (p. 2). The term 'AR' was coined

in 1973 by Tom Caudell and David Mizell, referring to “overlaying computer-presented material on top of the real world.” (ibid., p. 3).

Azuma (1997) defined AR through three characteristics: the combination of real and virtual; real-time interactivity; and three-dimensionality (p. 2). Later, Azuma et al. (2001) clarified the definition by stating that an AR system supplements the real world with virtual (computer-generated) objects that appear to coexist in the same space as the real world. While many researchers broaden the definition of AR beyond this vision, we define an AR system to have the following properties: real and virtual objects in a real environment. AR operates interactively, and in real time. Registers (aligns) real and virtual object with each other. Note that we do not restrict this definition of AR to particular display technologies, such as a head-mounted display (HMD). Nor do we limit to our sense of sight. AR can potentially apply to all senses, including hearing, touch, and smell. (p. 34)

Arth et al. (2015) note that Azuma’s original definition in addition to Milgram and Kishino’s continuum are, “commonly accepted as defining augmented reality” (p. 6). The two together provide the basis of the idea of AR, as well as other types of XR, in the context of this research. AR is situated on the reality–virtuality continuum in Figure 15.

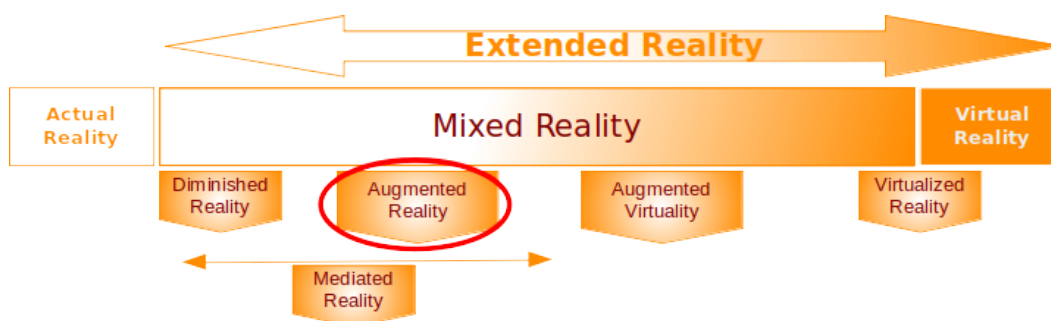


Figure 15. Augmented reality in reality–virtuality continuum is seen to have more virtualization than diminished reality, but less than augmented virtuality.

AR is applied for several purposes, such as easy and intuitive collaboration, interaction, integration of digital information, and mobile computing (Schnabel et al. 2007, p. 4). AR has also been used increasingly in vocational training in a plethora of fields, such as industry, medical training, maintenance assembly tasks, and the military. This is because it offers safety and performance improvement in training the skills needed in dangerous occupations, easy implementation, and realistic learning experiences (Chiang, Shang, and Qiao 2022, p. 9).

2.3.3.2 Augmented virtuality

Augmented virtuality (AV) is less known than AR, and the amount of applications and research is significantly lower. While AR means virtual elements augmenting reality, in AV, real objects are augmented by the virtual environment. For example, a real-time feed of a character situated in a virtual environment could be counted as AV, perhaps in a video conference in a virtual environment. In comparison, filters situated on top of a character would represent AR. In Figure 16, AV is positioned on the continuum.

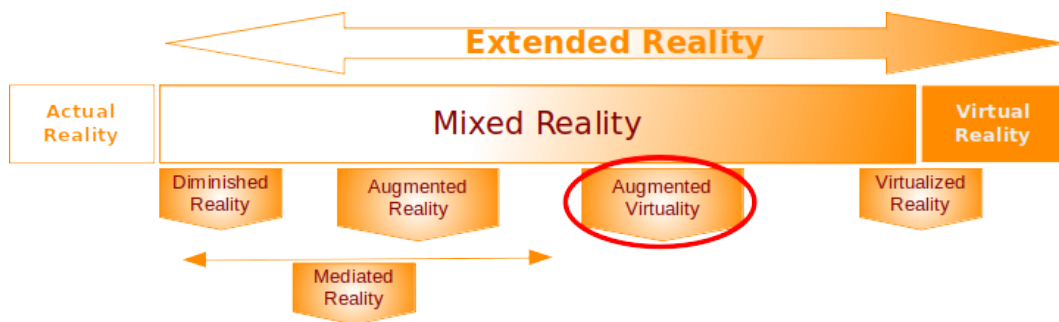


Figure 16. Augmented virtuality on the reality–virtuality continuum is situated between augmented reality and virtualized reality.

AV has been used, for example, in remote collaboration (see, e.g., Regenbrecht et al., 2003), teaching (see, e.g., Ternier et al., 2012), hazard recognition (see, e.g., Albert et al., 2014; Bhandari et al., 2019), and teleoperations (see, e.g., González et al., 2021).

Howard and Davis (2022) conducted a systematic literature review and meta-analysis of 29 studies focusing on rehabilitation programs. Their interest was in the design characteristics of AR and AV. They found many types of applications of AV for this purpose. For example, in a virtual gym, an image of the user appears via camera. The user receives instructions from a virtual trainer and can watch themselves performing activities. (p. 2). However, these studies often discuss AR and AV together as MR (ibid., p. 3). Howard and Davis found no statistically significant difference between the results of AR- and AV-based solutions in terms of improving users’ physical capabilities (ibid., p. 9). Overall, these solutions “improved user outcomes, but many design characteristics of MR programs do not influence effectiveness” (ibid., p. 14).

2.3.3.3 Other types of MR

There are some studies on other types of MR, but these categories remain largely conceptual. *Amplified reality* is left out from this current version of the reality-virtuality continuum, but since it has been included in some previous continuums, it is introduced to be able to justify why it was excluded. Amplified reality is situated closest to actual reality on several reality-virtuality continuums. The concept was presented by Falk, Redström, and Björk (1999) who asserted that amplified reality means enhancing physical objects with virtual properties that are “equally available to all users or everyone present” (p. 276). Those properties are embedded parts of the object, not superimposed virtual properties like in AR. “An amplified object is self-contained in regard to its properties” (ibid., p. 276).

Falk et al. (1999) see one of the key differences between amplified and augmented realities in, “the proprietary rights to the end information” (p. 276). Where in AR, the user of the equipment is in control of the information, in amplified reality the control is in the amplified object. For example, when having a conversation, a user of AR equipment may receive information about a person with whom they are engaged in conversation. Therefore, the control is in the hands of the AR user instead of the person that becomes an object of observation. Falk et al. compare this with similar situations in actual reality. People who become objects of observation in those situations can at least choose what to wear, how to behave, what to say etc. Thus, to an extent, they are partly in control of how other people see them. Falk et al. state that amplified reality resembles this, and with embedded publicly available properties, the control of the information is owned by the object of observation. In collaboration, this means that the user of amplified reality decides what others get to ‘know’. (ibid., p. 276)

The only definition of amplified reality found is that of Falk et al. (1999). From then on, the definition has only been quoted a few times with no further development. This leaves the concept quite vague, and it is difficult to determine what is and what is not amplified reality. For example, Schnabel et al. (2007) gave a debatable example of amplified reality when stating that re-painting the walls, thus altering reality, is amplified reality (p. 10). In comparison, they mention that wearing AR glasses gives an impression of the color being changed, while in reality, the colors have not changed. However, I do not see how painting a wall would be amplified reality rather than just actual reality. If they are to be part of XR, the elements need to be virtual, albeit embedded, as defined by Falk et al. (1999, p. 276).

In the search for previous research, only three solutions of amplified reality were found. The first was a dating application, Lovegety, introduced by Iwatani (1998).

Takeya Takafuji, the executive of Erfolg that manufactured Lovegety and Tamagotchi, stated the product was very popular in Japan, and the firm shipped 350,000 Lovegety units in the first couple of months after release. The device had three modes: talk, karaoke, and get2. The owner of the Lovegety unit chose a mode, and the device searched for all the Lovegety holders of the opposite sex using the same mode and located within a five-meter radius. When a person fitting the parameters was found, the device flashed lights and beeped to alert the holders to each other's presence. Lovegety is introduced in a YouTube video¹. A screenshot of the video is seen in Figure 17.

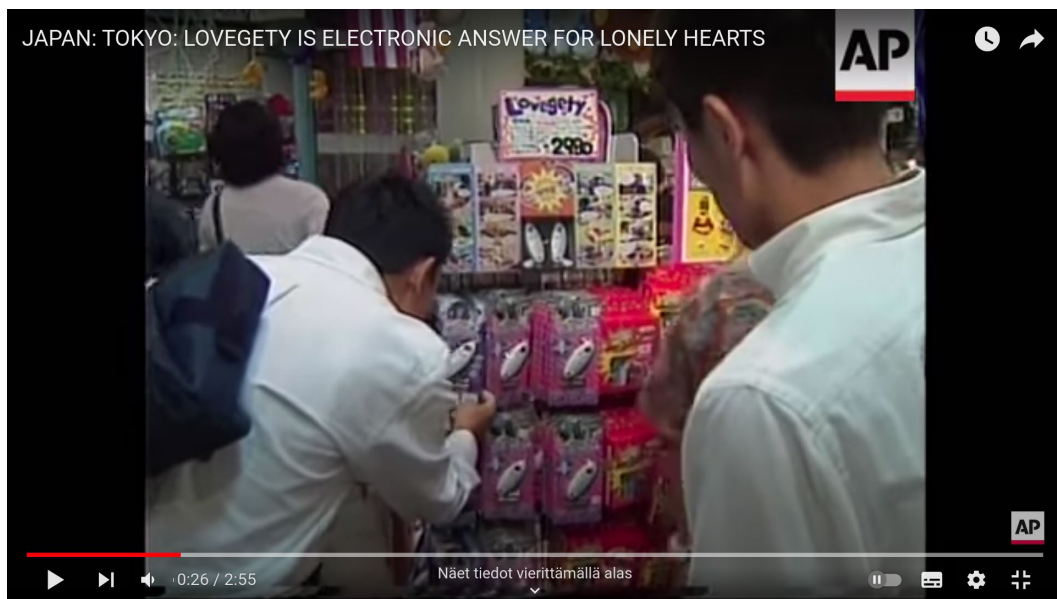


Figure 17. A screen capture of an introductory video of Lovegety on Youtube.

Another solution of amplified reality, the Hummingbird, was introduced by Falk et al. (1999). It was “an interpersonal awareness device that supports the awareness of presence between individuals in a group” (p. 15). A third application was BubbleBadge, introduced by Falk and Björk (1999). BubbleBadge was a wearable public display, connected to a hidden wearable computer. The approach means the interaction with a wearable computer was “shifted to the viewer, rather than the wearer, of a wearable device” (pp. 318-319).

At this point, it no longer seems sensible to count amplified reality as part of XR. Overall, the outcome rests in the definition of virtual. What is on the displays of computers or smart phones was previously considered virtual on the basis that it is artificially made and computer-generated. When it comes to XR, what is virtual also needs to be registered in 3D, which is not the case on a screen. From this

¹ <https://www.youtube.com/watch?v=O9Y-Viqlkjc>

perspective, it is difficult to see how Lovegety, Hummingbird, and BubbleBadge could be part of XR. If they are counted as part of XR, the same applies to the whole IoT, which makes the concept extremely broad. Therefore, it is justified to exclude amplified reality from the reality–virtuality continuum.

In the reality–virtuality continuum suggested in this research, the first type of MR, closest to actual reality is *diminished reality* (DR). Lepetit and Berger (2001) posit that DR removes objects from real video sequences (p. 1). DR is often seen as part of AR, but it is also a subject of research in its own right. For example, Azuma (1997) stated that, “besides adding objects to a real environment, Augmented Reality also has the potential to remove them” (p. 9) thus counting DR as a feature of AR. Azuma et al. (2001) use an AR-based virtual building replacing an actual building in the location to illustrate this (p. 34). They state that even though some researchers view diminished reality as a reality of its own, they see it as a subset of AR (ibid., p. 34).

Since one of the central features of AR in its definition is that virtual elements are added to the real environment, it is justified to see diminished reality as its own concept. Compared to, for example, X-ray vision, the difference lies between seeing through objects, and removing objects. In Figure 18, diminished reality is situated on the continuum; now closer to actual reality than on previous continuums. The reason for this is that on the continuum, the greater the number of virtual elements, the closer the type of XR is to a completely virtual environment, VR. Diminishing real objects does not necessarily mean adding virtual elements, as in AR, and therefore DR is now placed closer to complete actual reality than AR.

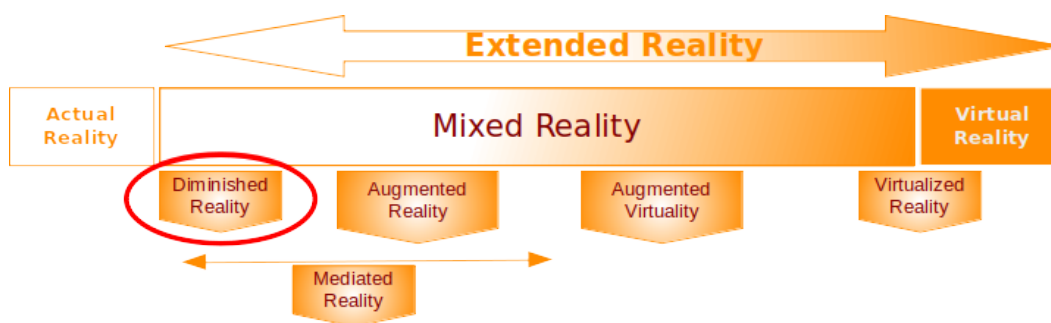


Figure 18. Diminished reality on the reality–virtuality continuum, right next to actual reality.

Several applications of DR have been developed. According to Lepetit and Berger (2001), there are for example, applications for special effects for the broadcast industry, and applications for urban design that assist in visualizing how a certain area would look after a new construction is built, removed, or replaced (p. 1). Krombholz-Reindl (2016) was interested in privacy solutions in the age of

wearable and ubiquitous computing. He had three suggestions that could be classified as DR, even though he does not use this term. Instead, he talks about privacy enhancing technologies that are meant to preserve digital privacy. The problem he aimed to resolve was that of people being recorded with wearable cameras, such as Google Glass, without realizing it. This is a compromise of privacy (p. 53). All the solutions he suggests give control of the information to the object, so they can decide not to be observed but instead blurred in the image stream of wearable cameras. DR has also been applied, for example, to self-driving vehicles (Ikeda et al., 2018) and in architectural and environmental design (Eskandari and Motamedi, 2021).

In the continuum suggested in this research, *mediated reality* overlaps DR and AR. Mann (1994) introduced and defined mediated reality as follows:

The general spirit of what is proposed, like typical AR; includes adding virtual objects, but also includes the desire to take away, alter, or more generally to visually 'mediate' real objects, using a body-worn apparatus where both the real and virtual objects are placed on an equal footing, in the sense that both are presented together via a synthetic medium. (p. 1)

Mann (1994) also adds real-time as one of the features of mediated reality. He defined the concept of mediating as “augmenting, enhancing, deliberately diminishing, or otherwise altering” (p. 2). Grasset, Boissieux, Gascuel, and Schmalstieg (2005) defined mediated reality as “the concept of filtering of our vision of the real world with and by virtual information realized with a linear or non-linear filter (in contrast augmented reality just uses an additive filter)” (p. 21).

Later, Mann (2002) described mediated reality as a broader concept that included MR, AR, and VR, with VR being situated as part of AR. He viewed the realities from perspectives other than just the relation between reality and virtuality. According to Mann, the continuum represents mixing, but he also considered modulation. For clarity, in this research, the focus is strictly on the viewpoint of the reality–virtuality continuum. Therefore, mediated reality is positioned so that it partially overlaps with diminished reality and AR (see Figure 19). This is because it includes some features of these realities.

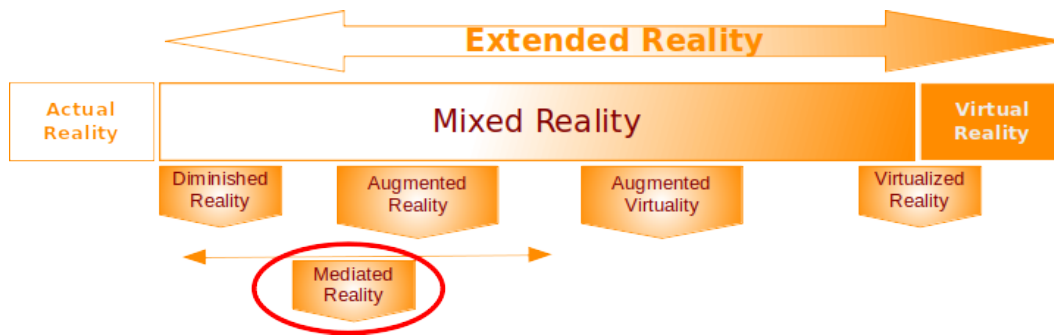


Figure 19. Mediated reality on the reality–virtuality continuum has a new type of location, where it collapses with diminished reality and augmented reality, even approaching augmented virtuality.

Implementations of mediated reality have been reached with the combination of cameras fitted in HMDs, “body-worn processing, and/or bidirectional wireless communications” (Mann 1994, p. 1). The first implementation was a “lightspace glass,” that was referred to as a “Reality Mediator” (RM). It was introduced in a hypothetical form, and was imagined to enable, for example, reversing the presentation of objects left to right, making the user colour-blind to real objects, or “toning down” surroundings and highlighting text on an HMD screen. (ibid., pp. 2–4).

Grasset et al. (2005) studied interactive mediated reality. They stated that applications of mediated reality are used in, for example, “industry (adding of color/material to a scale mock-up), art (visual assistance during realization of a sculpture), and also in rapid prototyping or packaging design (adding photometric properties)” (p. 21). They refer to Bandyopadhyay, Raskar, and Fuchs (2001) as an example of mediated reality. However, Bandyopadhyay et al. focused on a dynamic spatial AR system for applying virtual paint on real objects (ibid., p. 1).

Mann (1994) was worried about privacy issues and claimed that if people have to be exposed to video surveillance, they could have their own recordings produced by wearing mediated reality equipment as well. This would reduce the possibility of organizations using surveillance to falsify surveillance data. (p. 13)

Virtualized reality was developed and introduced by Kanade, Narayanan, and Rander (1995). Their study presents virtualized reality as a visual medium that “delays the selection of the viewing angle till view time” (p. 69). The study generated data for virtualized reality by recording events with many cameras situated so that they could shoot the event from every angle.

With the definitions of virtualized reality, comparison with VR seems to be central. For example, Kanade et al. (1995) defined virtualized reality as an improvement of VR because even though VR enables moving in a virtual world, it is usually created artificially by simple CAD models and therefore lacks fine detail. In contrast, virtualized reality virtualizes a real world (p. 69).

Kanade and Rander (1997) define virtualized reality as, “an immersive visual medium that lets the viewer select a (possibly time-varying) viewing angle at view time, freely moving throughout the virtualized event in ways even a mobile camera present at the event site could not” (p. 34). Rander, Narayanan, and Kanade’s (1997) definition compared virtualized reality and VR. The study found that while virtual reality provides viewer-controlled; 3D; and immersive views of a virtual environment, virtualized reality instead, “constructs full 3D representations of dynamic events from multiple video streams” with a modeling technique (p. 277). The findings highlight that VR is more suitable for virtual spaces than for re-creating real events. However, Ding et al. (2020) included a simulation of the real environment or things in VR, so this difference is debatable (p. 96966).

Virtualized reality is positioned on the continuum in Figure 20. Because of the similarities, it partially overlaps with VR. Whether virtualized reality still needs its own category or is just a subset of VR is debatable. Nevertheless, virtualized reality has been included in the continuum as its own concept because of the main difference in virtualizing reality instead of consisting of artificial virtual elements like VR. There is a difference, for example, if surgery is practised in a virtual, made-up operating room or in a virtualized version of an actual operating room, where the surgeon will later complete operations. In the latter case, the surgeon can also practice the location of actual objects in the operating room.

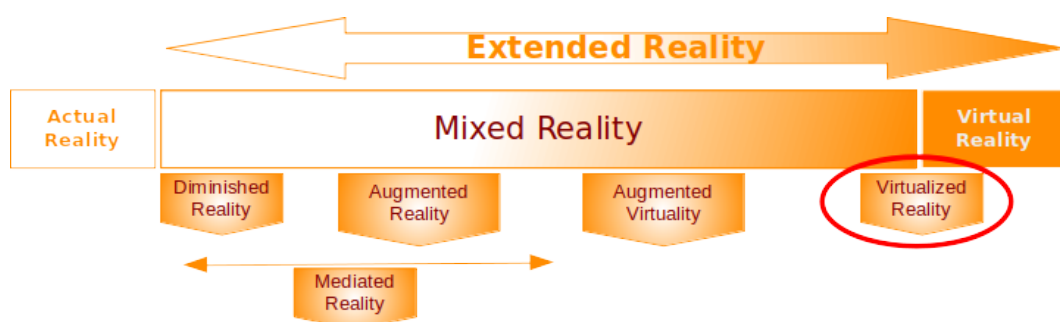


Figure 20. Virtualized reality on the reality–virtuality continuum now partly collapses into virtual reality, yet partly remains under the concept of mixed reality.

Virtualized reality has been used in training environments, surgeries, tele-robotics maneuvers rehearsals, telepresence by “performing transcription and view generation in real time,” and the entertainment media to give viewers a choice of angle from which to watch a basketball game or a concert performance (Kanade et al., 1995, pp. 69-70). Later, virtualized reality has been applied, for example, in real-time photorealistic virtualized reality interfaces for remote mobile controlled robots (Kelly et al., 2011), QoS-aware service continuity (Abdah, Barraca & Aguiar, 2019), and a “novel technique for estimating the damping parameters of materials from recorded impact sounds that probabilistically models ... external factors” (Sterling, Rewkowski, Klatzky & Lin, 2019).

All in all, other types of MR are less familiar and not at the core of development interests. Therefore, seeing MR as a whole instead of focusing on the differences between various types of MR is justified and may be useful for developing more flexible applications and technologies. In the service of technical communication, multiple possibilities may be rendered useful in changing use contexts and organizations. XR also brings challenges with it. A new challenge to the field of technical communication is related to issues of privacy and security, introduced in the next sub-chapter.

2.4 Issues of privacy and security

Privacy and security issues are highlighted in this research because they are new risks in the design of technical instructions. These issues have not been a topic of interest in this field previously since these challenges are not significant with traditional media to deliver technical instructions. However, adding XR to the list of possible technical instruction media prompts privacy and security issues arising from XR’s constant collection of massive amounts of data. Privacy and security are emerging research topics in the field of XR (see, e.g., De Guzman et al., 2019; Happa et al., 2019; Rauschnabel et al., 2018; Maloney et al., 2020; Wang et al., 2022). XR is not the only invasive new technology, and therefore, privacy and security issues should become a new topic in technical communication in general, owing to technological changes.

Privacy, in the context of this research, means data privacy. Kokolakis (2017) defined this concept as “concerned with controlling whether and how personal data can be gathered, stored, processed, and disseminated” (p. 123). Salimian (2018) defines privacy as “the ability of an individual to control the terms under which their personal information is acquired and used” (p. 31). According to Salimian, issues of privacy may cause strong emotions (ibid., p. 31). These are

fundamental concerns when it comes to using XR-based technical instructions. The user's privacy, and the privacy of passers-by, is always compromised because the equipment cannot situate the virtual elements without continuously collecting data from users and their surroundings.

Security, in this research relates to the concept of computer security. Adams et al. (2018) define security as "protection from danger," and computer security "relates this danger to ... human misuse rather than computer malfunctions" (p. 337). According to Salimian (2018), the concept of security, similarly to the concept of privacy, involves data about the user and how those data are used. Furthermore, the concept focuses on data concerning others, such as collaborators, passers-by, and employers, and how such data are used. It additionally includes the system itself. (p. 31) Security issues are also crucial with XR-based technical instructions as there is a requirement to protect sensitive data on both users and the organization in question.

There is a long tradition of research on privacy and security. The research includes an ongoing debate on the main causes of privacy and security issues. While some scholars focus on users and their lack of knowledge or interest (see, e.g., Alqahtani & Kavakli-Thorne, 2020, p. 121; Happa et al., 2019, p. 6), some highlight technology, applications and their ability to collect a plethora of data and the unpredictable possibilities to use those data (see, e.g., Zhang, 2020, p. 2; Li et al., 2021, p. 1793; Jana, 2014, p. 3). Scholars further highlight the poor usability of functionalities intended to enforce privacy and security (e.g., Krombholz-Reindl 2016, pp. 109–127). While all the points are important, knowing the target group in design work is crucial. The products should not be designed from the perspective of what the designers feel should exist given some awareness of the potential users. Rather, the products should be designed from the perspective of what users would actually do with them. For example, if a protective method is such that users, in reality, will not complete it, it is useless. Therefore, a re-design will be required if the users do not seem interested or do not know enough.

The designers of XR-based technical instructions have to be content with the existing technological solutions, and usually also the security measures of the applications, even though they are usually not designers of XR technology. Privacy and security risks have not been top priorities in delivering technical instructions. With XR-based technical instructions, two special kinds of privacy and security issues need to be identified. First, XR is based on situating virtual elements in real time in the right places in relation to the user. To be able to do this, the XR equipment needs to continuously recognize and record, for example, the location and position of users, their eye gaze path, and their surroundings. This is done in

a very detailed manner and the data gathered can include private and sensitive information on the user, any passers-by, and even company secrets (see, e.g., Zhang, 2020; Li et al., 2021; Jana, 2014). Collecting, processing, transferring and storing those data expose the data to accidental leaks and targeted attacks at any phase of XR data handling. Therefore, it is important to identify the risks and act to protect the data.

Second, in the MR context, privacy and security must be managed in both real and virtual spaces simultaneously. According to Salimian (2018), the fact that MR integrates physical and virtual spaces results in the need for both physical privacy actions in a virtual space (e.g., keeping a document folder closed) and virtual privacy actions in a physical space (e.g., revealing a document on a virtual display) (p. 31).

The designers of XR-based technical instructions also have to know their target group's attitudes to these new privacy and security challenges. According to Rauschnabel, He, and Ro (2018), people may be aware of risks without this knowledge necessarily impacting their behavior. Instead, people may feel that they have control over the device because they can, for example, turn it off when they want to. People may also belittle the need to secure personal data, and have difficulties in realizing the nature of possible consequences. Some accept that they are simply living in a world with no privacy (p. 381). To counter these attitudes, at the very least, the users can be informed about the risks they face when using XR equipment for work purposes. They need to be aware of what data are collected on them, how the data are used, and how the data are protected. However, it is unlikely that users will become experts on privacy and security issues. Therefore, solutions that protect the users' and organization's privacy in the best possible way with the least possible effort should be selected. However, in the context of technical communication, according to literature searches, research on privacy and security issues is in its infancy.

2.5 The TIER model

In the TIER model, the central concepts defined above are intricately connected. The complete structure of the TIER model is introduced in Figure 21, and explained below. As presented above, the TIER model includes features of technical instructions combined with features of XR. The model is based on theory but is intended for practical application to design technical instructions as well as a basis for research.

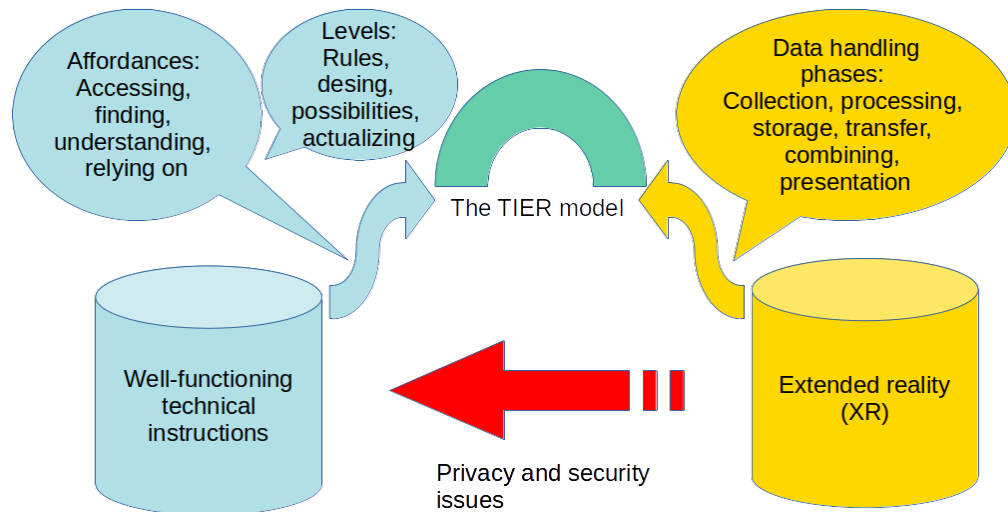


Figure 21. The complete structure of the TIER model includes the affordances and levels of well-functioning technical instructions, and the data handling phases of extended reality.

The central contribution of this research is the TIER model. The TIER model is based on the dual nature of technical communication: theory and practice. It is a user-centred approach to the design of XR-based technical instructions for technical communication professionals. The TIER model can be used to analyse, design, and test XR-based technical instructions. It is also used as a framework in several parts of this research, introduced in more detail in Chapter 3.

In the field of technical communication, different models of various approaches and aims for solving various challenges have been popular research topics for decades (e.g., Carradini, 2020). For example, Colombini and Hum (2017) suggested a framework and model for combining quantitative reasoning with the rhetorical know-how of technical writing pedagogy in a productive manner. They aimed to develop a method for creating user-centred and effective documents. Funk et al. (2015) developed the General Assembly Task model as a standardized means for designing AR-based instructions for assembly tasks. Their model includes both task-dependent and task-independent measures. They also suggest two cheap, easily reproducible assembly tasks that, according to the authors, “cover most tasks found at assembly workplaces in industrial settings” (p. 5).

Moreover, within usability studies (see, e.g., Alexander, 2013; Sapienza, 2004), there is plenty of research focusing on different types of XR delivering different types of instructions (see, e.g., Tzimas et al., 2019; Doshi et al., 2017; Zauner et al., 2003; Hoedt et al., 2017). Usability tests of XR-based technical instructions are

rarer, with the focus often on technological solutions (e.g., An et al., 2020) instead of the instructions. However, some exceptions exist, such as Fussell et al. (2019), who focused on a mixed methods approach to learning, satisfaction, and effectiveness of VR-based instructions. Their results indicated positive results with high user satisfaction and learnability among novice and expert participants. However, novice users were less comfortable than experts and found tutorials more mentally demanding than experts. They also found it more enjoyable. According to Fussell et al., the enjoyment “is likely due to a novelty effect from using VR for the first time” (p. 33). Furthermore, despite the reported ease of the task, observations showed that some participants encountered problems and had to attempt the task several times. The problems were mainly related to participating in the VR environment and not knowing how to do so most efficiently (ibid., p. 34).

However, there seems to be a lack of research on and methods for organized, comparable models and tools for designing XR-based technical instructions. Therefore, in this doctoral thesis, such a model is developed step-by-step. The TIER model is designed to be combined with the knowledge and expertise of technical communication professionals. Furthermore, the model is designed to be flexible in the era of rapid technological changes so that it can be modified for other contexts.

The TIER model consists of two essential elements: the affordances of technical instructions; and the phases of data handling in XR. The affordances of technical instructions are accessing, finding, understanding, and relying on. These affordances, when actualized, enable technical instructions to fulfil their main purpose; guiding users operating with technical devices. In the TIER model, the affordances are seen through the levels of rules, design, possibilities, and actualizing. The level of rules focuses on laws, regulations, and principles, which are required for good guidance. The level of design concentrates on how ideal technical instructions should be designed. The levels of possibilities and actualizing are user-centred. Possibilities focus on what affordances users notice and actualizing how they will or will not choose to act upon the affordances they have noticed (Rantakokko, 2022b, p. 27). The aim is knowledge acquisition, management, and transfer from professionals to users, focusing on research and practice.

The phases of data handling in XR are collection, processing, storage, transfer, combining, and presentation (Rantakokko, 2022a, p. 82; Rantakokko, 2022b, p. 27). That process-based view reveals how data are handled in XR as a medium for technical instructions. Combining the features of XR as a medium and the

technical instructions that are delivered makes it possible to identify and analyse possibilities and challenges of XR-based technical instructions in all the phases of design and testing. That is also true of different organizations with different types of instructions, use contexts, and user groups.

The TIER model can be used as a framework in organized design processes in the following phases (Rantakokko, 2022b):

- 1) Appraising valid laws, regulations, and recommendations for the type of instructions with each affordance (the level of rules); for example, what is required to access the instructions;
- 2) Considering all the desired features and those that should be prevented, compared to the affordances (level of design, focusing on technical instructions); for example, what kind of safety-related guidelines are needed in the instructions;
- 3) Comparing the results with the phases of data handling in XR in detail to ensure that each phase supports each affordance (level of design, focusing on XR as a medium for instructions); for example, how privacy and security issues relate to accessing data at every phase of the XR data handling; and
- 4) Testing that the users recognize the affordances present in the design (level of possibilities) and that the affordances can be actualized in real situations (level of actualizing); for example, do the users understand phase-by-phase instructions in a maintenance task, and can they perform the task with the instructions. (pp. 30–31)

The phases are repeated in an iterative process until the desired outcome has been reached.

The relations of the central features of technical instructions and XR are introduced in the matrix table of the TIER model in Article 3, introduced in Chapter 4. Examples of various ways to use the TIER model in this research are explained in the methods chapter below.

3 METHODS

This chapter details the methodology used in this research. The research adopts a qualitative, exploratory approach with some experimental ingredients as it focuses on an area that has not, to date, been extensively researched. The aim was to uncover the possibilities and challenges of mediating technical instructions through XR. As a result, the TIER model was developed

There are several definitions of qualitative research, and an ongoing discussion of what it is (e.g., Aspers & Corte, 2019). Qualitative research can be defined, for example, as a research approach that “aims to address questions concerned with developing an understanding of the meaning and experience dimensions of humans’ lives and social worlds” (Fossey et al., 2002, p. 717). It is also defined “as an iterative process in which improved understanding of the scientific community is achieved by making new significant distinctions resulting from getting closer to the phenomenon studied” (Aspers & Corte, 2019, p. 160).

Exploratory research in social sciences can be defined in various ways as well. Swedberg (2020,) highlights that discovering something new and interesting is the core aim. The risk is not knowing beforehand if there will be a novel outcome (p. 17). Stebbins (2001) highlights the importance of two orientations in exploratory research: “flexibility in looking for data and open-mindedness about where to find them” (p. 5). Overall, the definition of exploratory research is vague. Despite this, it is used to define the core of this research. The choice is based on not knowing initially if the holistic approach would prove usable and possible. There was a possibility that the holistic approach would be unsuccessful. However, the risk did not materialize and the results indicate that the holistic approach is usable and functional. The methods and purposes for which they are used in this research will be discussed in detail in sub-chapters named and numbered, as shown in Table 1. Below, they are explained in numerical order, starting with 3.1, identifying and defining central features.

Table 1. Methodological sections aiming to uncover possibilities and challenges of XR as a medium for technical instructions.

3.1 Identifying and defining central features	
Thematic analysis	<ul style="list-style-type: none"> • Satellite model • Mind mapping • Text segmentation
3.2 Developing a theoretical model	
Grounded theory	
3.3 User-centered approach	
Affordance lens	

User-centered design	
3.4 Analytical framework	
The TIER model	<ul style="list-style-type: none"> • Design of pilot test • Results of pilot test • Taxonomy of XR → Scenario-based design
3.4 Pilot test of the TIER model	
Mixed methods	<ul style="list-style-type: none"> • Qualitative • Quantitative
Case study	<ul style="list-style-type: none"> • Experimental laboratory study • Remote study
Data gathering methods	<ul style="list-style-type: none"> • Observation • Questionnaire • Interview

The theoretical framework of this research is summarized in the TIER model. The model describes the mutual relationships of the two cornerstones of this research: technical instructions and XR. In addition, the TIER model offers a foundation for empirically exploring the opportunities and challenges of using XR to deliver technical instructions and supports a user-centred, iterative design process of XR-based technical instructions. The main concepts concerning both corner stones are first identified and defined via *thematic analysis* combined with *text segmentation* (Guest, MacQueen & Namey, 2012), *mind mapping*, and *satellite modelling* (Nuopponen, 2016). The central features of technical instructions are seen through the *affordance lens* (Gibson, 1979; Lanamäki et al., 2016), as described in sub-chapter 2.2. This approach highlights that users are central to the design process, thus making the TIER model user-centred and instilling *user-centred design (UCD)* principles (e.g., Abras, Maloney-Krichmar & Preece, 2014; Clariana & Strobel, 2008) into focus.

Grounded theory was used to develop the TIER model as a theoretical framework (Glaser & Strauss, 1967). The TIER model was *pilot-tested* as a *case study* with human participants. *Mixed methods* (Lund, 2012) combined qualitative and quantitative data in the pilot test. Both *laboratory* and *distant research* (see, e.g., Isohella, 2018; Andreasen et al., 2007) were used. *Data gathering methods* were *questionnaires*, *observation*, and *interviews*. Furthermore, *the TIER model* has been used as an analytical framework in both design and analysis of the results of experiments, and in Chapter 5, where different types of XR are discussed. In Chapter 5, *scenario-based design* (see, e.g., Carroll, 1999) is applied as a supporting method. The following sub-chapters detail the research methods utilized in this research.

3.1 Identifying and defining central features

As this research aimed to explore possibilities and challenges that XR brings to the context of technical communication when it is used as a medium to deliver technical instructions, the central features of both technical instructions and XR were first identified and defined. Identification of central features of technical instructions started by defining that the central purpose of technical instructions is to help users operate a technical device (Markel, 2012, p. 3; Rantakokko & Nuopponen, 2019, pp. 57–58). The central features of technical instructions were examined to identify which features are required for technical instructions to be well-functioning. From this basis, it would be possible to see how XR can assist or complicate the fulfilment of technical instruction tasks. Therefore, the central features of XR had to be analysed to map its features in relation to the core features of technical instructions.

Thematic analysis was applied to uncover relevant dimensions and features of well-functioning XR-based technical instructions. The thematic analysis includes six phases: 1) familiarization with data; 2) generating initial codes; 3) searching for themes; 4) reviewing themes; 5) defining and naming themes, and 6) presenting results (Nowell et al., 2017, p. 4).

Data familiarization was conducted separately for both core topics, technical instructions, and XR. The first step was a selective qualitative literature review (e.g., Schryen, 2015). This approach was chosen to gain broad insight into the subject from different viewpoints. Literature was searched from Google Scholar and the information-seeking portal Finna, thus enabling access to both open and limited-access research. Furthermore, the references of articles and books read were also used in literature searches. The first search words were simple ones, such as “augmented reality” or “technical instructions”, forming the process based on the findings. For example, when different types of XR were found in the literature, each one was subsequently searched for separately. The approach ensured the researcher became familiar with the topic and how it was discussed in previous research, despite different views and terminology. Both topics were observed from several different viewpoints during this stage.

Next, relevant sources were selected for analysis based on the selection criteria derived from a holistic perspective. The approach thus focused on the common features of different types of technical instructions and different types of XR rather than differences. Since this topic is relatively new, the criteria also included possibilities and challenges that could be relevant to the field. The sources revealed concerns related to XR technology, such as challenges to privacy and security, the

physical consequences of using XR, and high equipment costs. Information sources excluded focused on highly technical facets of XR technology, such as characteristics of different display solutions or other fields completely, like architecture (Rantakokko, 2022a, pp. 81-82). Four sources were chosen to analyse technical instructions, and 24 sources contributed to the analysis of XR. These sources are detailed in Chapter 4.

Initial codes were generated using text segmentation. Guest et al. (2012, Chapter 3) mention that text segmentation is a practical tool to aid thematic analysis. With this method, not only single words are recognized, such as occurs during coding, but instead larger sections, if needed, such as sentences, paragraphs, or even complete topics. In this research, text segmentation was a crucial step because the terminology and approaches of different studies vary in terms of technical instructions and especially XR. Therefore, it was necessary to focus on the larger texts before proceeding further to the coding and thematization phases, which revealed the different ways the same topics were discussed in the sources. The text segmentation method made it possible to test alternative coding options for the text segments to observe which approach would be practical for the research undertaking. The text segmentation was conducted with a mind-mapping technique based on satellite modelling developed by Anita Nuopponen (2016). This technique was used to organize the findings and identify their commonalities and relations. The combination of these approaches enabled the chosen, holistic approach to both topics.

For technical instructions, initial inductive coding revealed 470 initial codes (Rantakokko & Nuopponen, 2019, p. 57). In the context of this research, these included all requirements based on laws, acts, and guidance regarding how to write well-functioning technical instructions discovered from the sources.

The core of technical instructions in this research is seen as assisting a user in operating a technical device, and XR is seen as a medium to deliver these instructions. This results in the central focus being how these instructions can be delivered from the professional to the user via XR. Therefore, the initial coding of XR entailed investigating and selecting an approach that would enable the identification of how the features of XR can be seen in relation to the central features of technical instructions. In other words, how the features can support or cause challenges for the designed-in affordances of technical instructions.

With this approach, the initial codes of XR identified were, for example, “what kind of data is available” and “how is data expressed” (Rantakokko, 2022a, p. 82). Furthermore, XR equipment also collects data in order to function. Therefore, the instructions can be seen as *instructional data* and data collected by the equipment

as *collected data*. From the sources, it was identified that in XR, data goes through different *phases*. For example, the data can be stored and presented to someone.

In the *search for themes*, the aim of this research was kept in mind. Four main shared factors for the initial codes were derived with technical instructions based on the initial coding. These were the need to access, find and understand the information given and rely on the instructions and information they included. The approach to XR as a medium for technical instructions resulted in themes related to how data is handled at XR in different phases. Six phases were found. These relate to collecting, processing, storing, transferring, combining, and presenting the data.

The identified themes were then *reviewed*, ensuring no exceptions remained in the sources. Rather, each separate finding would fit on one, and only one theme found in the analysis. The process of searching for themes from the literature and reviewing them continued in an iterative manner until saturation was reached and all the findings fit in the same theme-based categories. In other words, according to the grounded theory explained in the next sub-chapter, at this point, the possibility of a theory was seen with a patient, persistence, and iterative data comparison (Walker & Myrick, 2006, p. 552).

The central features of technical instructions were *presented* in Article 1 (Rantakokko & Nuopponen, 2019), and the central features of XR in Article 2 (Rantakokko, 2022a). Articles included precise *definitions and names* of the themes found. Articles are introduced in detail in Chapter 4, the summary of the articles.

3.2 Developing a theoretical model

The method used when formulating the TIER model was grounded theory, developed by Glaser and Strauss (1967). Grounded theory is a practicable approach for developing new theoretical frameworks, like the TIER model. The core of grounded theory is comparative analysis in that data collection and analysis are simultaneous, and each data fragment is compared with the other data fragments (Glaser and Strauss, 1967). This is how it was used in this research as well. Grounded theory was necessary to direct the research to reflect the aims and previous results (see, e.g., Glaser & Strauss 1967).

Later, Glaser & Strauss developed the theory in different directions. Walker and Myrick (2006) examine that split in their article on the Glaserian and Straussian versions of the theory. The central aspects of this ongoing debate focus “on the

researcher's role, activity, and level of intervention in relation to the procedures used within the data analysis process" (ibid., p. 547). Both of these separated versions of the grounded theory include the same basic process of gathering data to compare and categorize it and then form a theoretical sampling to generate a theory from core categories developed based on the findings in the process (ibid., p. 550).

Both versions of grounded theory were applied in this research. In different phases of this doctoral research, the emphasis has been on different versions of the split views of Glaser and Strauss. For example, at the beginning of the coding process, the method of this research was closer to Glaser in the sense of letting the data speak for itself (Glaser, 1992, p. 50) instead of using analytical tools (Strauss & Corbin, 1998). In the phase of analysing the central features of technical instructions and XR, the approach was more Glaserian, as verification was seen as part of the constant comparison (Walker and Myrick, 2006, p. 555).

However, after that, it seemed wise to conduct a separate verification phase because the holistic approach to both topics is so large, thus being more Straussian than Glaserian. It was important to see that this approach was valid and applicable. Therefore, first, the analysis of XR was carried out with another set of literature as described in sub-chapter 4.2. Subsequently, the central features of technical instructions were freshly examined (see Chapters 2.1 and 5).

Furthermore, in the process of developing the model, the direction led towards the Straussian view as the matrix tables were used in order to make the model usable and enable both detailed and broad views for different purposes. The use of the matrix tables of the TIER model is introduced in sub-Chapter 4.3 and Chapter 5. While Glaser saw this approach as too detailed and limiting, in this research, it was necessary because, as Strauss and Corbin (1998) suggest, it helped to see beyond the obvious (Walker & Myrick 2006, pp. 556 - 557). Without the matrix tables, it would have been impossible to see the actual influence of each XR data handling phase on every affordance of technical instructions. Therefore, while following the original theory and proceeding from Glaserian to Straussian views, both versions of grounded theory are found usable. The most applicable version varies based on what is researched, and sometimes both can be used to gain the ideal result.

Glaser and Strauss (1967) highlighted that the core of the emerging theory is revealed from categories as they develop and become related and as the relations accumulate (p. 40). This core then guides the theoretical development. The result of the theoretical development in this research was the TIER model. In order to create the TIER model, there was a need to find the cores of two sets of data first separately, which meant identifying central features of technical instructions and

XR. While the core of technical instructions could be discovered without many previously set aims, the core of XR was sought with a specific purpose, guided by the previous research phase.

There were many possible ways to code and theme XR, such as different technologies aimed at different senses (i.e., visual, auditory, haptic, olfactory), the technological solutions (such as different solutions for XR glasses or mobile against static, etc.), or the development timeline. Technological solutions, for example, offered an interesting view of the development, possibilities and limitations of the current applications of XR. Based on thematic analysis, any approach would be equally suitable. However, in the context of this research, XR had to be analysed from the perspective of identifying how the central features of XR can support XR-based technical instructions to fulfil the main purpose of aiding the user of a technical device, and what type of challenges the use of XR may cause.

Then, these central features (cores) needed to be arranged in relation to one another to find their common core. The model was formed via an iterative grounded theory process with constant comparison. Matrix tables were used to place each feature of XR in relation to every feature of technical instructions to see the impact. That process employed existing empirical examples until the saturation point was reached (Rantakokko, 2022b, p. 29), and therefore, the core was found.

Grounded theory has attracted some criticism. For example, Cutcliffe (2000) brought up conflicting opinions and issues found in grounded theory in separate studies across several decades. Key issues found in Cutcliffe's research were sampling; creativity and reflexivity; the use of literature; and precision within grounded theory (ibid., p. 1476). These exceptions are present in this research as well. The first exception Cutcliffe pointed out pertains to the risks of remaining purely in data, and being completely free of previously set purposes during the sampling is challenging (ibid., p. 1483). In this research, the intention rested on placing the features of XR in relation to the features of technical instructions in a manner that would enable the development of a model. Therefore, this research was not free from previously set purposes, which particularly affected searching for the central features of XR, as XR was seen as a medium for technical instructions, and thus the view on XR was determined.

The second issue of creativity and reflexivity also occurs in this research. In this research, it is acknowledged that the researcher holds a certain position derived from factors such as expertise and social and cultural experiences, and bias concerning the studied topic. The situation is common in studies applying

grounded theory (Cutcliffe, 2000, p. 1478). In this research, choices on issues such as the user-centred approach had to be made in every phase, each affecting the course of the research and subsequent choices.

According to the principles of grounded theory, literature research should be avoided (Cutcliffe, 2000, p. 1480). However, in grounded theory, this means that data is separate from literature, and literature would thus guide how the data is understood, instead of letting the data show the path. In this research, literature was the data. This approach in model development has been used by, for example, Mead and Bower (2000). Therefore, literature research was needed to find the data. However, the model was formed without further literature review of different models, thus letting the data from previous research phases lead the process. The fourth issue introduced by Cutcliffe was precision with grounded theory (Cutcliffe, 2000, p. 1481). As explained above, exceptions to the theory during this research indicate that this issue is present in the current research, and grounded theory is applied with exceptions. However, the core of the grounded theory method remained strong in this research, especially in the formation of the TIER model described in this chapter.

3.3 User-centred approach

User-centred design (UCD) aims to raise the users to the centre of the design process to ensure relevance, usability, desire to use, and alliance with values (see e.g., Dopp et al., 2019; Karat, 1996). In this research, the purpose of technical instructions is to guide users in using a technical device, which leads to a user-centred approach. Central features of technical instructions and XR are identified and combined in a TIER model to support this purpose.

When the themes were searched in the context of technical instructions, the concept of affordance was recognized as offering a potential starting point. The affordance lens is user-centred because its core is how the user interacts with the object. The concept of affordance was chosen to identify such features of technical instructions that support their main purpose of helping the users. For example, Lanamäki et al. (2016), Treem and Leonardi (2012), and Majchrzak et al. (2016) have highlighted the usefulness of the affordance lens in research concerning different technologies. This research focuses on the possibilities and challenges of XR as a medium for technical instructions. Seen through the affordance lens, the central features of technical instructions formed the affordances of accessing, finding, understanding, and relying on. (Rantakokko & Nuopponen, 2019, pp. 57–58)

Based on the theoretical ideas of Lanamäki et al. (2016), who introduced four alternative stances on the concept of affordances (pp. 129–136), four levels of affordances that can be present simultaneously were formed. The resulting levels highlighted the focus on users even more. First, on the level of rules, the focus is on what is required from the technical instructions so that they could be optimal for the users. The second level, the level of design, is based on the actual design process of XR-based technical instructions keeping users in mind. The levels of possibilities and actualizing are completely user-centred, as they focus on what affordances users do or do not notice, and how they either act upon or ignore the affordances they notice. (Rantakokko & Nuopponen, 2019, pp. 63–64)

Furthermore, the aspect of levels encourages the use of a process-based approach in the design of XR-based technical instructions. The TIER model is designed for an iterative design process, where the phases of design (level 2) and phases of testing (levels 3 and 4) are repeated until the desired outcome is reached and the instructions are well-functioning. According to Baek et al. (2008), iterative design is expected in UCD (p. 662). Baek et al. state that approaches to design can be either product-oriented or process-oriented. Process-oriented approaches require focusing on the whole design process rather than just the product itself, and when complemented with an aspect of sociotechnical features, they encourage the involvement of the users in the process. Then, not only tools and techniques and procedures are highlighted, but also people, networks of roles, relationships, and tasks as well (ibid., pp. 660–661).

As Abras, Maloney-Krichmar, and Preece (2014) state, in UCD, the users influence the design process and are usually involved during requirements gathering and usability testing (p. 1). In the pilot test of the TIER model, users are involved in the testing phase (levels of possibilities and actualizing). The approach of UCD has also been applied in the following aspects of the experiment design.

In UCD, preconceptions have a significant role (e.g., Clariana & Strobel, 2008, pp. 339–341). In Article 4 of this research, the method for identifying user preconceptions involved presenting the instructions in both regular video and XR form. The method supported gathering user estimations of XR as a medium for technical instructions before and after using the instructions in XR form. A simple VR-based structure with no added virtual elements was chosen to enable the use of exactly the same instructions to be delivered via two different media.

Given Gibson's original definition of an affordance included all the possible functionalities that an actor notices in an object, here, flaws in instructions are seen as affordances alongside designed-in features. The choice was motivated by

the definition of affordances as possible functionalities, thus not requiring that only designed functionalities are affordances (Gibson 1979; Norman 1999).

Products are often introduced to the market with existing usability issues. There can be a range of reasons, including a lack of user testing, which renders it important to understand how users cope with technical instructions mediated by XR when conditions are not optimal. Therefore, in this research, a designed-in glitch was included in the instructions to see if the users would notice it and how they would act upon it if it were noticed. It was assumed this would indicate how they may act upon unknown flaws before the test phase. As the task would be a LEGO construction, the glitch selected was to include a block of a different colour to that described in the instructions. In an iterative process of designing and testing XR-based technical instructions, it is important to realize that “users typically know more than what they can initially verbalize” (Baek et al., 2008, p. 661). Therefore, data was gathered in test situations by several methods, introduced in Chapter 3.5.

3.4 Analytical framework

The TIER model was applied in this research as an analytical framework on three occasions: 1) the design of the pilot test; 2) analysis of the results of the pilot test; and 3) the comparison of different types of XR in Chapter 5.

When the *pilot-test* was planned, the choices on how the TIER model would be applied were made in the design phase. The TIER model was designed to be used during the complete design process of XR-based technical instructions. Therefore, it can be applied fully or partly, depending on the purpose. For pilot testing, it was deemed suitable to apply the TIER model partly to test its validity before conducting larger projects with the assistance of the TIER model. Therefore, the experiment was designed to be simple, easy to repeat, as well as cost and time efficient.

Nevertheless, the experiment needed a fully immersive experience to simulate the actual use of technical instructions in an XR context. The task was a simple LEGO construction, which would be instructed via VR. LEGO has been used in research on technical instructions before (e.g., Funk et al., 2015; Korn et al., 2013). This type of task also enabled easy modifications if necessary. That was important because the TIER model is designed to be easily applied in the design process of any XR-based technical instructions.

The understanding and relying on affordances were emphasized because it was anticipated that the affordance of accessing would be irrelevant because the participants would access the instructions based on the experiment design. The affordance of finding was deemed somewhat irrelevant, particularly considering the simple structure of the test. However, it was not ruled out that some results could fit into these categories, despite the focus being on something else. The levels of possibilities and actualizing were chosen as they focus on the testing phase of the design process. The presentation phase of XR data handling was chosen because it is the phase in which the designed instructions are shown to the users, which is useful for the next iterative design phase. The sections of the TIER model used in experiments are presented in Figure 22.

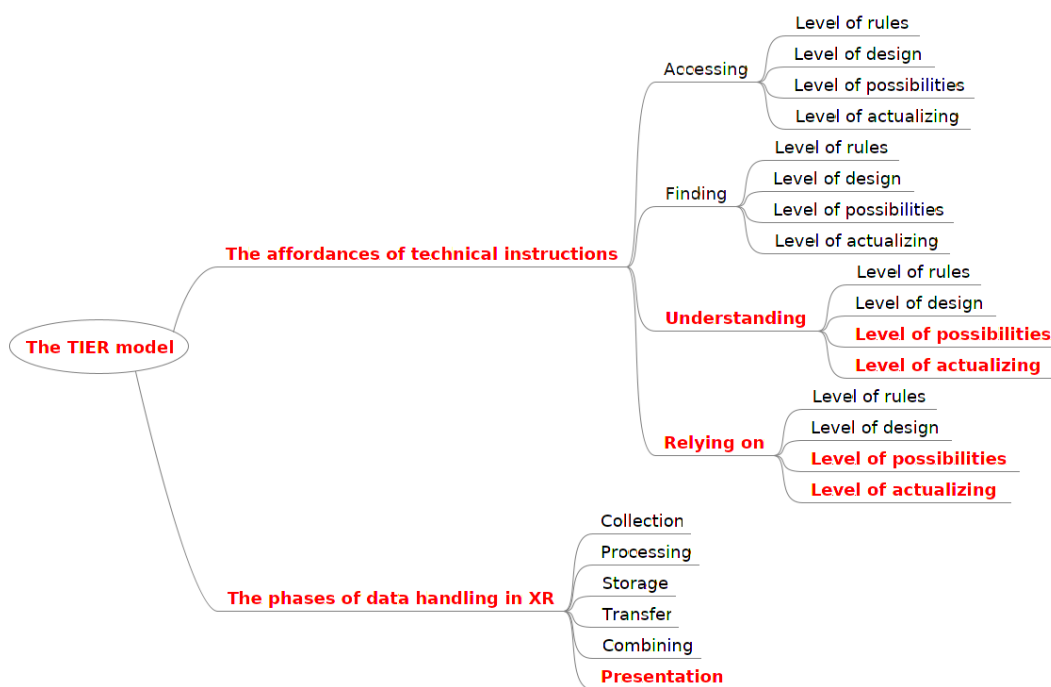


Figure 22. Sections of the TIER model used in experiments are the levels of possibilities and actualizing of the affordances of understanding and relying on, in relation with the presentation phase of data handling in XR.

The TIER model was applied to *analysing the results*. The analysis was conducted by listing all the observations of the experiments: the answers to the questionnaires; transcribed observations; and the answers to the interviews. These observations were then situated in the matrix tables of the TIER model, categorizing them in relation to the affordances to which they were connected. After this, the observations were compared to one another to see if there were differences based on the variations of the test designs. Table 2 introduces an

example of a general structure of such a matrix table. Each question and every anomaly will be listed in the matrix table.

Table 2. General structure of a matrix table of the results related to the affordance of accessing.

Accessing	
Questionnaire responses	
Test 1	Test 2
<i>Questionnaire questions related to affordance of accessing</i>	
Replies categorized	Replies categorized
Anomalies observed	
Level of possibilities	Level of actualizing
<i>Anomalies observed during the experiment related to the affordance of accessing</i>	
Noticed / Not noticed	Influence on the experiment and actions taken

The tables included participant answers, and anomalies noticed during observations of the experiments. The pilot test results are reported as matrix tables in articles 4 and 5. An actual design process of XR-based technical instructions would continue by modifying and further developing the instructions designed in the required ways based on the testing phase results. For example, the reported failure of the online connection in Table 1 would require a solution of how the instructions could be used in such a situation. An iterative process would continue with periods of testing and re-designing until the desired outcome is reached. Reports of each iterative phase would remain in the form of the matrix tables to be used, if necessary, later on.

Finally, the TIER model was applied to inspect the *features of each type of XR* and how they relate to the affordances of technical instructions in Chapter 5. Because of the limited number of applications of every type of XR in the service of technical communication, a *scenario-based design* is applied to conduct a comparison. Carroll (1999) defines scenarios as visions and descriptions of typical and significant user activities early and continuously in the development process. According to Carroll, these scenarios are stories that “support reasoning about situations of use, even before those situations are actually created” (p. 44).

Scenarios are very useful in design situations, as they can, for example, help coordinate design actions with the assistance of reflection. The scenarios are both concrete and flexible and enable multiple views of an interaction. Therefore, it is possible to manage changing design situations with different kinds and amounts

of details and consequences of different design decisions. (Carroll, 1999) In the context of this research, such scenarios are used in Chapter 5 to illustrate how different types of XR could be used in typical cases where technical instructions are required, which reflects how different types of XR are useful in different kinds of tasks. Some types have an ongoing development interest, while some are almost theoretical. Therefore, there are no useful actual examples of the use of every type in similar activities.

As the scenarios in this research are used to illustrate the special features of each type of XR, and to enable comparability, the chosen scenarios are brief and on a general level. This choice is made because of the broad approach of this research. When a scenario-based design is used in decision-making in an organization, the scenarios should be more detailed stories based on specific situations and use cases.

The types of XR are separated from each other on the reality–virtuality continuum based on the proportion of virtual and real elements they contain. These features substantially influence the affordances of accessing and finding. The focus is at the level of design. The XR data handling phase of presentation is chosen as a focus. This is because it is the phase in which the features of XR become visible when the instructions are presented to the user. Therefore, these parts of the TIER model are illustrated in Figure 23.

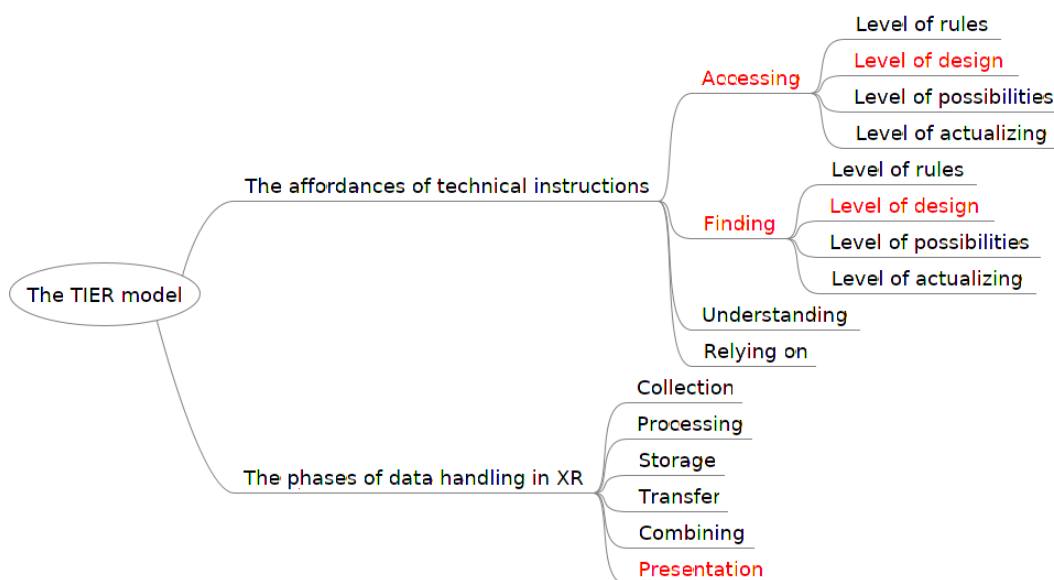


Figure 23. The aspects of the TIER model in Chapter 5 include the level of design of affordances of accessing and finding, complemented with the presentation phase of data handling in XR.

According to the TIER model, the XR data handling phase of presentation can improve the likelihood that the affordances of accessing and finding will be actualized in real situations, as shown in Table 3.

Table 3. Effects of the presentation phase of data handling in XR on the affordances of accessing and finding.

The Phases of XR Data Handling	The Affordances of Technical Instructions	
	Accessing	Finding
Presentation	Improves	Improves

As seen in the table, the presentation phase of XR data handling can improve the likelihood of the affordances of accessing and finding to become actualized in a use situation. Different types of XR are compared in Chapter 5 using the scenario-based approach. The complete matrix table with all the effects of data handling phases to each affordance is introduced and explained later in Table 3.

3.5 Pilot test of the TIER model

The TIER model is aimed to be used in the design process as a whole, when developing XR-based technical instructions. It includes the levels of possibilities and actualizing, that exist in relation to testing and using XR-based technical instructions. Therefore, as a part of the process, it was necessary to also undertake pilot-testing to observe preliminary effectiveness indicators and be prepared to modify the model where and when necessary.

The pilot test of the TIER model was conducted via three experimental tests. The experiments utilized *mixed methods* combining *remote* and *laboratory studies*, using *observation*, *questionnaires*, and *interviews* as *data-gathering methods*.

Mixed methods – qualitative and quantitative - were utilized in the pilot test based on the purposes of each experiment. Lund (2012) identified four possible advantages of using mixed methods in research: 1) to answer complex research questions; 2) to produce a complete view of the topic; 3) for more valid inferences; and 4) to develop new theoretical insights (p. 157). The data in the pilot-test of the TIER model were mainly qualitative. Nevertheless, quantitative aspects were added to the research design, for example, by timing how long it took to complete the task or how many times the instructions were viewed. The pilot-test involved combinations of participants being present (Tests 1 and 3) and remote testing (Test

2). Remote testing is an established method often used in usability testing (see, e.g., Isohella, 2018; Andreasen et al., 2007). In this research, it helped avoid physical contact due to the COVID-19 situation at the time.

Mixed methods are a useful approach to testing the XR-based technical instructions because quantitative results may offer valuable information that can be used in combination with qualitative results. For example, the researcher should investigate if the user reports the instructions are easy to use but spent more time with them than average. Furthermore, there may be a phase in a workflow that seems more time-consuming than others, which would indicate that the instructions for that phase have some flaws. In this research, the test situations were recorded and transcribed to find out such cases. A mixed-methods approach delivers more information from the combination but consumes more resources.

Furthermore, surprising situations like pandemics or conducting research across long distances can challenge the mixed-methods approach. The key to combining testing methods is flexibility. For some testing phases, brief remote testing is enough, at least when it is later complemented with larger tests conducted with various methods. In the pilot test experiments, the participants were instructed that their task was to evaluate the instruction they received.

Data was gathered through several methods to ensure wide-ranging results. Therefore, the methods included observation, questionnaires, and interviews, in this order. These methods were chosen to support each other so that interviews could be focused on the results of observation and questionnaires to deepen the understanding.

It is important to remember flexibility and purpose when gathering data. The more methods are used, the wider the results and the resources required. For example, in this pilot test, Test 2 was conducted remotely, and the questionnaires were the only method for data gathering. Continuity was gained with a follow-up test in a laboratory environment. Some features remained impossible to validate with the remote test, as the data was not gathered with other methods than the questionnaires. In a design process of real XR-based technical instructions, there is a need to consider in which phases of a testing process there is a need to validate results with more methods and when it is enough to have only questionnaire answers. Below, the purposes of each data-gathering method of the pilot tests are explained.

In Test 2, the questionnaire was the only method used for data gathering because Test 2 focused on the users' evaluations, their preconceptions, and what they thought about the XR as a medium for technical instructions. In other words, Test

2 was based on the level of possibilities. The main disadvantage of questionnaires is that they must be simple and concise to avoid being too long and complicated, reducing the quality of responses. Furthermore, if filled remotely, there is no way to ensure that the intended participant fills it instead of someone else. Although the issue was not relevant to this research, people with reduced literacy and poor access to email or the internet will likely be excluded (Phellas et al., 2011, pp. 184–185). Furthermore, questionnaires require strong hypotheses and a good grasp of the topic beforehand if they are to be useful. Even with open-field questions, participants are guided to think in a certain way based on what is asked and how. In the context of this research, these disadvantages were minimized in several ways, explained below.

Before Test 2, Test 1 had included largely the same question sets and was complemented by interviews to ensure the questions were correctly understood. Therefore, the questions seemed to be simple and understandable. Because the focus of these experiments was on testing the test process instead of the participants themselves, there was no great interference in the reliability of the study if someone else filled out the form instead of the anticipated participant. By inviting participants from among communication students and sending the material and instructions for the test to their student emails, it was expected that they would be able to participate if they had agreed to do so. The approach combining these measures, introducing the experiments in advance, and making participation voluntary was intended to increase response rates.

However, the questionnaires included questions that could not be validated without observation, such as whether the participants followed the instructed order of the activities. Questionnaires were a combination of open, closed, and fixed-choice questions. Open questions let the participant describe what they think about the topic in their own words. Closed questions have previously set alternatives, such as yes or no responses. Fixed-choice questions combine these by giving space to explain the closed question choice tapped. A Likert-type scale was used in questions that included users' estimations. The combination of such questions was intended to elicit the participants' opinions in the form of quantitative, comparable, and qualitative answers.

In Tests 1 and 3, questionnaires were complemented via two other methods: observation and interviews. In these tests, the participants were present. They were asked to complete the task and the questionnaires before the interview. The sequencing helped avoid the bias typical in face-to-face interviews, where the interviewee is influenced by the way the question is asked or tries to answer in a way that the participant anticipates that the interviewer would like (i.e., guessing

the correct answer as reported in Phellas et al., 2011, p. 183). The observation methods targeted objectivity. Recording the situation enabled timed transcription later on. Being present enabled the probing of occurrences that arose during the tests within the interview questions. It also enabled the continuation of the test in case some anomalies would happen.

Observation is an important method in addition to self-reporting methods because it may reveal biases, thus offering more reliable information (see, e.g., Kendall et al., 2004). In this pilot test, for example, participants typically did not mention the designed-in glitch in the questionnaire, and they carried out the task. However, when asked directly in the interview, they informed that they had noticed the glitch (Rantakokko, submitted; Rantakokko & Rousi, submitted). They had simply reasoned that it was not relevant and therefore was not worth mentioning. As another example, one participant mentioned that the instructions were easy to use and still used remarkably more time watching them than on average.

The purpose of the interviews was to complement other data-gathering methods. Interviews were based on the previous sections of the experiment. The participants were asked open questions such as what they thought of the experience and what they meant by specific answers. The stage ensured that the answers were understood correctly and that the brief questions on the questionnaires were discussed in more detail if needed. Those participants who had been involved in Test 2 were also asked to compare the experiences.

The number of participants was small because the purpose was to pilot test the TIER model and to test the method on a small scale before investing more time and financial resources on larger tests. Furthermore, the COVID-19 situation limited the possibilities for safe tests, and thus the pre-XR test was conducted as an online version with only questionnaires as the data acquisition method. That is a valuable method for preliminary tests in a larger test process, but later it should be supported with more observation methods.

All in all, despite the limitations of the pilot-test, these methods offered enough information to meet the intended purposes: 1) The TIER model is indicated to be a promising method for the testing process of XR-based technical instructions, 2) It indicated to be functional for identifying user preconceptions, and 3) The TIER model indicated to be useful in recognizing whether the users are able to spot the errors, and if they are willing to report them. More tests are needed, as usual, after the pilot-test. After these results, wider test arrangements are reasonable to make.

3.6 Discussion of the methods

As introduced above, this research proceeded from collecting data relevant for defining the main features of well-functioning technical instructions (Rantakokko & Nuopponen, 2019), and XR as a medium for those instructions (Rantakokko 2022a), in order to develop a theoretical framework of the TIER model, to be used in practical work in the field of technical communication (Rantakokko, 2022b). In other words, this research has moved from data to theory, from the specific to the general. In the context of this research this means that based on grounded theory, the features of technical instructions and XR were identified from previous research, and been combined in a model to be used in developing XR-based technical instructions. Furthermore, applying the TIER model in different parts of this research has given necessary feedback on its functionality for different parts of the design process of XR-based technical instructions. Finally, empirically the model was pilot tested in three experiments (Rantakokko, submitted; Rantakokko & Rousi, submitted).

The combination of these methods aimed to identify and combine the central features of two topics into a new theoretical model usable in practice. Even though the pilot-test of this research included mixed methods, the emphasis of this research was qualitative.

This research adopted a qualitative method because of its common characteristics. Ormstron et al. (2014) listed the common characteristics of qualitative research as 1) providing an understanding of the social world; 2) methods that are non-standardized, adaptable, and sensitive to the social context; 3) data is detailed, rich and complex; 4) analysis methods that respect complexity, nuances, and uniqueness; 5) possessing an openness to emerging categories and theories when conducting analysis and interpretation; 6) offering detailed descriptions of the topic researched, "grounded in the perspectives and accounts of participants;" and 7) having an approach which is reflexive and acknowledges the researcher's perspective and research process (p. 4). These characteristics are present in this research in the following ways.

The aim of this research was to add an understanding of the possibilities and challenges of XR as a medium to deliver technical instructions. This aim was approached with a combination of adaptable and non-standardized methods introduced above to harvest complex and detailed data in the form of a holistic TIER model. Different technical instructions and types of XR were considered through the analysis methods to retain the uniqueness of any XR-based technical instructions design process. The result was a new theoretical model to be used in

practice, developed with the principles of grounded theory. Detailed descriptions are given, for example, of the types of XR. However, this research aimed to generate a holistic view and highlight common features. The research process is highlighted in this research, as the approach is process-based and every phase is based on the previous.

Grounded theory was applied to enable the formation of the model. It was utilized to identify the foundational facets of this model for developing XR-based technical instructions by isolating essential themes arising in related literature. As there is a lack of comparable models of specifically this type focusing on the systematic design, development, and analysis (method) of technical instructions, the TIER model is independently examined in this PhD research. The literature research indicates that models with similar goals to the TIER model seem to be lacking.

The pilot test of the TIER model focused on obtaining participant feedback on the XR-based technical instructions to signal whether the TIER model could be used in an iterative testing process of actual XR-based technical instructions. The goal was to identify and analyse user preconceptions, behaviour, and design performance (Rantakokko, submitted; Rantakokko & Rousi, submitted). The instructions were developed specifically for this experiment to avoid bias through familiarity (Casaló, Flavián & Guinalú, 2008).

The combination of the methods used and described above indicates that the basis of the TIER model is functional. However, it still needs more validation after the pilot test. The next reasonable method would involve interviewing technical communication practitioners and instigating more involved test processes to validate the TIER model and ascertain if the model is functional in a complete design process of XR-based technical instructions, not only in certain phases. However, no single method fits every possible situation, and therefore, despite the holistic aim, it is next to impossible that the TIER model would be an exception.

3.7 Ethical considerations

The ethics committee of the University of Vaasa approved the research design. The ethical considerations of this research are focused on the empirical tests conducted towards the end of this PhD research. When human participants are involved, ethical considerations should always be part of the process (see, e.g., Rutstein, 1969; Edgar & Rothman, 1995).

Participants were informed that participating in this research is completely voluntary and that they have the right to withdraw from the research without

explaining their reasons. According to the General Data Protection Regulation (GDPR), participants were also informed on how their data would be used, to what extent, how it would be stored, and when it would be destroyed. They were also told that no one would use recordings but the researcher to protect their privacy and reassure them of confidentiality so they would be less nervous and cautious during the experiments.

In the context of this research, the privacy and security of the participants was considered. While these issues were highlighted as new challenges in the field of technical communication, the approach of the pilot tests was specially considered from the viewpoint of privacy and security of the participants.

Due to the fact that participants were few, the bare minimum of personal data was collected to ensure identities would not be revealed. Therefore, in this research, the solutions were chosen to be as non-pervasive as possible. For example, the smartphone used to watch the instructions in Test 1 was the researcher's own. Because of this, it could be ensured that the recordings would not be used to profile the users. The recordings were stored securely, transcribed, and destroyed. While the self-reporting data of the experiments was saved, it did not include names or any personal information. Data were saved according to numbered codes for tracking purposes by the researcher. All personal data were stored separately.

The COVID-19 situation was taken into consideration. The number of participants was kept small, and remote research was used in Test 2. Masks were worn during face-to-face contact, which was limited to only the researcher and one participant at any time.

In the field of technical communication, ethical considerations have been an inseparable part of the work and research for decades (see, e.g. Dombrowski, 2000; Dragga, 2009; Wicclair & Davis, 1984; Clark, 1987; Etambakonga, 2021). As Clark (1987) states, ethical perspectives should guide the work of both practitioners and academics in technical communication (p. 190). The dual nature of technical communication is present in ethical considerations as well. Clark separated practical and academic ethics, which have different emphases and viewpoints. The professional perspective focuses on the immediate boundaries of the work, while the academic perspective focuses more on legal and moral questions, with a broader viewpoint (*ibid.*, pp. 190 – 192). Despite the viewpoint on the ethical debate, the researcher considers ethical considerations a natural part of the work of a technical communication professional, which reflects technical instructions being designed for various audiences, including users from different cultural backgrounds, with physical and psychological restrictions, and of various ages. The instructions need to be inclusive rather than exclusive.

The ethical issue highlighted in this research is the new challenge concerning privacy and security. Furthermore, the safety of the user of various technical devices is a priority (see, e.g., Smith, 1990; Sauer, 1996). Safety, privacy, and security may be linked (see, e.g., Nakamura & Ribeiro, 2019), as well as ethical considerations with such issues (see, e.g., Adams et al., 2018). From this aspect, it is natural to consider privacy and security issues in technical communication when they arise with the use of emerging technologies.

4 SUMMARY OF THE ARTICLES

This chapter provides details of the articles featured in the dissertation. The articles related to this research focus on developing and testing the TIER model. Articles 1 (Rantakokko & Nuopponen, 2019) and 2 (Rantakokko, 2022a) introduce the definitions of the central features of technical instructions and XR. While time has passed since the publication of Article 1, the main ground remains. Article 2, while fresh, still is a “picture of its time” and development proceeds. These features are brought together and concerning each other in Article 3 (Rantakokko, 2022b) in the form of the TIER model, which is the main contribution of this research.

The TIER model is then pilot tested with three experiments. The pilot test results are reported in Articles 4 (Rantakokko, submitted) and 5 (Rantakokko & Rousi, submitted). The role of the pilot test was to see if the TIER model can be used in a testing process of XR-based technical instructions and if it indicates functionality, making larger follow-up tests reasonable to conduct. Together, the Articles 1–5 describe and justify the design process and preliminary results of testing the TIER model.

4.1 Affordances of Extended Reality to Technical Communication – Towards a Theoretical Model²

The first article of this dissertation (Rantakokko & Nuopponen, 2019) was published in Finnish. The article focuses on technical instructions as guides for users to operate a technical device. The grounded theory approach identified four affordances of technical instructions when analysing a limited number of carefully selected sources focusing on the laws, regulations, and guidance for effective instructions. The first affordance identified was *accessing*. If the affordance of accessing is to be actualized, the instructions must be designed and made available for the intended users. The second affordance identified was *finding*. After accessing the instructions, the user should be able to easily find the necessary information from among the information as a whole. The third affordance was *understanding*. When the information is found, it needs to be understood. For example, a language that the user is familiar with should be employed. The fourth affordance was *relying on*. In this context, the instructions must be reliable, so the user would access them to obtain assistance and continue using them as necessary (Rantakokko & Nuopponen, 2019, pp. 58–61).

² Laajennetun todellisuuden tarjoudat tekniselle viestinnälle – kohti teoreettista mallia

Furthermore, Article 1 focuses on how to apply the affordance lens to technical instructions. For the purposes of theory building, the affordances were seen through four different levels and categorized further into three distinguishing factors (relational ontology, origin, and receiver). This deepened the range of the affordances so that they could be approached from different viewpoints. The four levels of the affordances of technical instructions were identified as rules, design, possibilities, and actualizing. The level of rules defines all the necessary and important features that must be included in technical instructions according to laws and regulations. It also includes the principles of good guidance. The level of design focuses on how these affordances are designed into technical instructions to be available to the user. The level of possibilities switches the focus to the user and all the affordances the instructions include for their use. The level of actualizing defines an actual situation in real life, where affordances either will or will not actualize for the user. (Rantakokko & Nuopponen, 2019, pp. 63–64) The levels are needed in the TIER model to deepen the focus and enable a phase-by-phase approach to the design of XR-based technical instructions.

These levels of affordances can also be approached through three distinguishing factors: ontology, origin, and receiver. For example, with the affordance of finding information at the level of rules, relational ontology focuses on the relation between instructions and rules to find information. In this context, origin represents the rules generated through social practices. The receiver is anyone who has accessed the instructions (Rantakokko & Nuopponen, 2019, pp. 62). The initial structure of the model is illustrated in Figure 24.

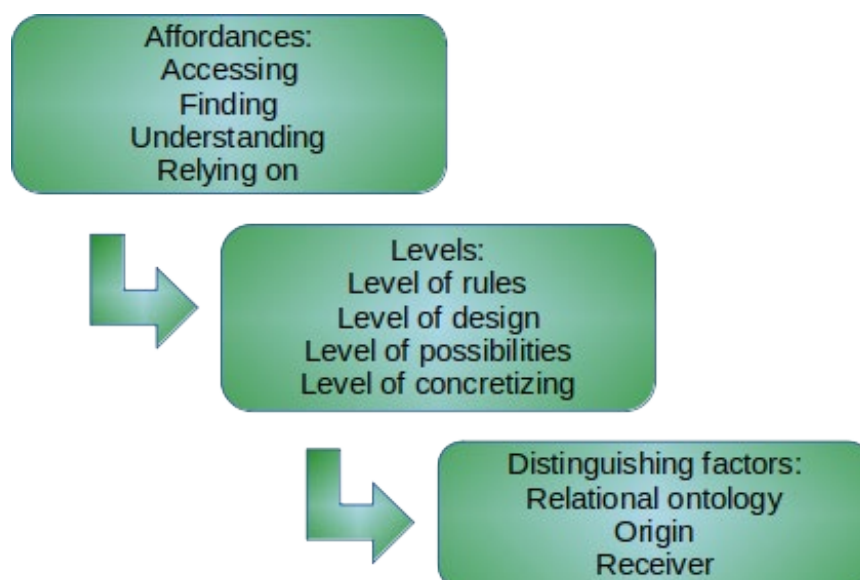


Figure 24. Affordances of technical instructions, their levels, and distinguishing factors used in the Article 1.

Building on these foundations and viewpoints, the TIER model began to take shape. Below is an extract from the first article, translated into English:

Based on the concept of affordance, it is also possible to create other, very different types of models. However, we believe that the body of the model formed in this way is versatile and suitable for examining different sources and including extended reality as the subject of thorough examination. The model is flexible and transformable according to how practices gradually change and how they also change laws and regulations. The model also makes it possible to examine the technologies that will be developed later and the ways to convey instructions with them. It can also guide the drafting of instructions, helping to focus on the essentials from all relevant viewpoints. (Rantakokko & Nuopponen, 2019, p. 65)

After the article was published, new relevant sources, such as updated standards and research articles, have appeared. Despite this, the fundamental starting points of this research have remained functional. Newer research supporting the sources of Article 1 is discussed in sub-Chapters 1.1.1 and 2.1. The small number of sources used in the analysis can be seen as a limitation of the research of Article 1. However, even though this approach was developed with a limited number of sources to the moment of analysis, they were carefully chosen to represent different points of view on technical instructions. It was always an option to alter the model during development in response to the research indicating elements were lacking or inaccurate. That proved necessary in the next step: distinguishing factors were left out from the following versions of the TIER model because as more research was added, the distinguishing factors seemed ever more irrelevant. Their presence complicated the picture and thus challenged the idea of a functional tool being produced.

However, as suggested in Article 1, it would be possible to add a more theoretical layer to the model that includes epistemic and cultural considerations. From a theoretical perspective, for example, considering the cultural understanding of a technical device might be a fruitful starting point for discussion. Nevertheless, it is less so for a practitioner because the professionals are expected to know the devices for which they are designing instructions. However, the distinguishing factors for theoretical use have been discussed in Article 1, and therefore they are free to be added to the TIER model if needed in specific theoretical instances.

Other changes to the model were not made during the research project since the base created in Article 1 functioned sufficiently for the research project purposes, and the approach of four affordances of technical instructions and four levels of affordances was functional. Article 1 was written with Anita Nuopponen; while the

author of this research focused on analysing the sources, Nuopponen suggested the affordances approach and wrote the parts on the concept. The author created a synthesis of the results from the affordance-based viewpoint.

The research then continued by searching for the central features of XR that would allow a comparison of the affordances of technical instructions. This process is reported in the second article introduced below.

4.2 Data Handling Process in Extended Reality (XR) when Delivering Technical Instructions

The second article (Rantakokko, 2022a) focused on understanding XR as a whole. The approach was to identify the central features of XR when it is used as a medium for technical instructions. Therefore, it was necessary to find a means to focus on the common features of XR (instead of the differing features) in a way that enabled comparison with the affordances of technical instructions.

The article is based on a literature review that thematically analysed 24 papers and four books (Appendix 1). These sources represented studies of different types of XR used in various tasks. As a result of the analysis and approach of how the data is handled in XR, six phases of XR data handling were identified: collection, processing, storage, transfer, combining, and presentation. It is important to realize that the literature review of an emerging technology does not remain fresh for long. New solutions (with their own possibilities and challenges) emerge while some fade away. A literature review, therefore, is an image of its time. However, with the sources used in Article 2 and introduced in Appendices 1 and 2, more recent research from different viewpoints has supported the observations rather than challenged them.

After identifying these phases, the analysis results were tested with another set of 13 different literature sources (Appendix 2). These sources focused on privacy and security issues because these issues are one of the main challenges that XR provokes since XR equipment needs to continuously collect data about the users and their surroundings to situate virtual elements in the correct places at the right time. Those data may include sensitive information. During the XR data handling phases, those data are vulnerable to leakage, misuse, or attack. While privacy and security issues are critical in XR-based technical instructions, research remains in its infancy (Rantakokko, 2022a, p. 76).

The central features of each phase of data handling in XR are introduced using examples from the sources retrieved in the literature review. These features

include the importance and role of this phase in relation to the affordances of technical instructions, the risks involved, and suggested measures to counter the risks.

Article 2 indicated that a holistic approach to XR is possible and that common features of different types of XR can be found. This research increased knowledge of XR as a medium for technical instructions, and highlighted the importance of realizing the challenges of privacy and security in the field of technical communication as a new phenomenon brought upon by new technologies. The next step was to examine whether the research results gathered permitted combining the central features of technical instructions and XR together, in relation to each other. Accordingly, the formation of the TIER model continued in the third article of this research project.

4.3 Creating a Model for Developing and Evaluating Technical Instructions that use Extended Reality

In Article 3 (Rantakokko, 2022b), the formation of the TIER model in an iterative process is described, and the TIER model is introduced by explaining each phase of XR data handling in relation to each affordance of technical instructions, from the viewpoints of the levels of rules and design. Examples of aspects to be considered in each phase were presented.

The TIER model was introduced in the form of a matrix table listing each phase of data handling and its effect on the affordances, shown in Table 4. This tabular style permits a simple comparison of what the TIER model enables.

Table 4. The basic structure of the TIER model (Rantakokko 2022b, p. 32)

The Phases of the XR Data Handling	The Affordances of Technical Instructions			
	Accessing	Finding	Understanding	Relying on
Collection	Occurs	Occurs	Occurs	Exists
Processing	Improves	Improves	Improves	Exists
Storage	Improves	No effect	No effect	Exists
Transfer	Improves	No effect	No effect	Exists
Combining	Occurs for a new data set	Improves	Improves	Exists
Presentation	Improves	Improves	Improves	Exists

In the matrix table, the term *occurs* refers to the relevant phase of XR data handling in which the affordance first emerges. For example, the affordance of accessing emerges when data is collected, and if the data is combined with other data, the affordance of accessing emerges for this new data set. (Rantakokko, 2022b, p. 31) The affordance of relying on is an exception in the matrix table, and is marked as *exists* on every row. The reason for this is that this affordance has or has not emerged before the process of design (Rantakokko, 2022b, p. 31). The potential users already have general experience with instructions, preconceptions that evoke attitudes, motivational elements, and emotions. All this already exists when the process of designing new instructions begin. Those aspects can and will be influenced during the process and must be considered. The impact of some phases is the possibility to *improve* the probability of actualizing the affordances. For example, collected data is more likely to be accessed if actively presented to the user. *No effect* is marked when the phase of XR data handling has already occurred, and the new phase does not have a significant impact. The reason for this is the temporal relation of the affordances. If the affordance of accessing has already actualized in the phase of data collection, there is no significant effect on the affordance during the next phases. (Rantakokko, 2022b, p. 32)

This research aimed to develop a theoretical model for use in practice. The purpose was to increase knowledge of XR as an emerging technology as a medium to deliver technical instructions. The need was obvious and called for (see, e.g., Tham et al., 2018). Therefore, this research was built on solid theoretical ground, and a user-centred approach was chosen instead of a technology-centred approach. Despite the theory-based starting point, the model is developed on the ground of the research focused on the practice of the field, and therefore it strongly emphasizes practical aspects. To deepen the connection to practice, the formation of the TIER model continued with pilot tests to validate preliminary results of the functionality of the TIER model and if the next steps to involve the professionals of technical communication would be reasonable to make. The results of the pilot test experiments were reported in articles 4 and 5.

4.4 Affordance-based Approach Towards Understanding User Preconceptions of XR-based Technical Instructions

Article 4 (Rantakokko, submitted) focused on establishing how user preconceptions and their development could be identified in relation to new technology during the testing phase of the design process of XR-based technical instructions. Another goal was to pilot test the TIER model to see if and how it

could be used to support an organized test process of XR-based technical instructions and the analysis of results.

The influence of preconceptions is important when designing technical instructions. Human cognitive processing includes preconceptions (see, e.g., Clark, 2013; Rasmussen & Vicente, 1989), which may be positive or negative or both, and have emotional connections (see, e.g., Russel, 2003; Norman, 2002). When technical instructions are delivered with new technology, such as XR, user preconceptions influence the user's attitudes and experiences in use situations (see, e.g., Karagozlu et al., 2019; Law et al., 2009).

Article 4 reports the results of Test 2 and relevant sections of the results of Test 3 in relation to preconceptions. Furthermore, as presented in Chapter 3.3., the instructions included a designed-in glitch: one LEGO block was replaced by a similarly shaped block of a different colour. The glitch was inserted to measure how the participants would solve the problem. It is possible that there will be flaws in a new set of XR-based technical instructions in real work situations, and it is important to understand how the users may act in such cases and how their decisions and estimations would affect both work processes and testing the designed technical instructions. In this research, the designed-in glitch tested how users would handle errors in technical instructions.

To be able to offer the same instructions in different forms, the chosen format of XR was VR. In Test 2, the instructions were delivered via video, and in Test 3, via VR equipment. The first experiment focused on evaluating the instructions to determine which affordances the participants noticed and to test the participants' possible preconceptions toward XR. The second test included acting upon the instructions. The purpose was to identify how the preconceptions may develop before and after involvement with XR as a mediator of technical instructions.

In Test 2, the data were gathered via questionnaires. The questionnaire included open questions on what flaws the users noticed in the instructions, and others on whether they thought the instructions were unreliable, and why. However, the glitch designed into the instructions was not usually mentioned by the participants. Instead, the participants stated that they noticed the glitch when asked directly. When asked why they did not mention the glitch despite noticing it, they answered that they had reasoned that the glitch was not relevant. This indicates that users tend to draw their own conclusions rather than mention what they consider trivial.

Furthermore, all participants who evaluated the instructions without attempting the building task reported that they would have been able to finish the task with

the instructions. However, most of them had not noticed the designed-in glitch. Therefore, while the exact task was impossible to complete because of the glitch, all the participants ended up either finishing the task in some form or believing that it was possible to finish the task since the wrongly colored block was irrelevant to them. This indicates that while *experienced understanding* was high, the *actual understanding* was questionable. In the context of this research, experienced understanding refers to how the participants assessed their level of understanding. Actual understanding refers to the observed level of understanding based on, for example, users' actions in relation to the instructions. Therefore, multiple methods for data gathering in the testing process are needed because the participants mostly either did not notice the designed-in glitch or did not mention it. Unintended flaws that are not known by the designer of the instructions are likely to remain unknown if the data of the testing process are only gathered via questionnaires and interviews. A designed-in glitch seems, therefore, a valuable tool for error detection.

In Test 2, some negative preconceptions about XR as a medium were indicated, and in Test 3, only marginal development of preconceptions was noticed. The affordance of relying on was relatively low. The users were not engaged with XR in Test 2, so their evaluations were largely based on their preconceptions about the technology. Five out of seven reported that they were willing to use XR-based technology in their work or studies, but mostly they stated that if they had a choice, they would prefer video instructions over XR-based instructions. Such preconceptions are important to realize in designing technical instructions to be delivered via new technology. That renders it possible to work towards improving not just the designs but people's attitudes during the design process. After Test 3, self-estimated reliance was high, and the users expressed a willingness to use XR in general. However, once again, users mostly preferred other types of instructions to the XR-based version.

The results cannot be generalised because the COVID-19 situation reduced the number of participants. Therefore, larger tests are needed to validate the results and to be able to compare differences based on background variables. For example, the possible differences in outcomes brought about by various starting pictures could not be identified. A baseline would have been useful to instil consistency of exposure (see, e.g., Kanade, Rander & Narayanan, 1997). Furthermore, there was no continuity in this pilot test. The first test's results were not intended to be used to develop the instructions. The process would have been iterative in a real development situation, which is also necessary for follow-up research. Despite the limitations, the TIER model seemed promising in terms of the purpose for which it was designed. The TIER model seems to offer a method for analysing and

comparing the results. Therefore, the TIER model is one way to identify the preconceptions of the users in an iterative test process.

4.5 XR-based Technical Instructions in organised Testing: User Behavior and Design Performance.

Article 5 (Rantakokko & Rousi, submitted) focuses on reporting on the systematic use of the TIER model in two experiments: Test 1 and relevant sections of Test 3. The research examines how the design of XR-based technical instructions is informed when the actions of users are considered in relation to new technology. In the same vein as Article 4, this article explores how designed-in and unintended affordances become noticed or remain unnoticed and actualized or ignored by users. In this article, special interest was placed on how user behaviour can be studied in the context of XR-based instruction interaction. Therefore, the approach and the focus of interest differed from Article 4. The approach was meta-experimental, meaning that in testing, the testing method and data collection were also research targets (Rantakokko & Rousi, submitted).

A sub-question was set in order to understand the level of reliance on the information delivered: To what extent do users rely on the details of the instructions – how much do individuals compensate for inadequacies by use of mental information contents (Rantakokko & Rousi, submitted, p. 6)? Therefore, the designed-in glitch mentioned before was also relevant to this article.

In Tests 1 and 3, XR-based technical instructions were delivered via two different sets of equipment. The TIER model was used to analyse and report the results featured in this article in the same manner as in Article 4. The actual instructions in these experiments played a smaller role, while the focus was on identifying properties within the design process of XR-based technical instructions based on user responses to affordances, whether designed-in or accidental. The same instructions for a LEGO construction were used as in Article 4, here with two sets of equipment and two different environments. The results were compared with the TIER model and analysed with the same matrix method presented in Article 4.

Some unexpected situations arose during the tests, which was anticipated since humans are unpredictable actors, and not all risks can be anticipated, which are some of the reasons why testing the instructions is crucial when delivering them via new technology (see., i.e., Eichler, Darivianakis & Lygeros, 2017; Spagnoletti & Resca, 2008). For example, although participants were instructed not to interact with the researcher during the test, they all did. They wanted to re-check the details of the research process and/or had questions about the equipment. The technology

used caused unexpected outcomes as well. For example, the Wi-Fi connection failed at the beginning of one test, and the equipment failed during another. The glitch in question caused the direction of the instructions to reverse 180 degrees multiple times, forcing the participant to do the same.

The results of these tests highlight the importance of an organized test process when using new technology to deliver technical instructions. The instructions in these tests were designed to be very simple, and yet several unexpected situations arose. Mostly, these anomalies were noticed via observation and discussion and were left out in questionnaires. Flaws noticed often remained unmentioned until directly asked about them. Therefore, observation is a crucial part of testing instead of merely asking for user evaluations (e.g., Gram, 2010). There are several possible reasons for flaws in evaluations, such as considering flaws noticed to be irrelevant, desire to be polite, or willingness to do as they think they are supposed to or to “succeed” in a test situation (see, e.g., Nederhof, 1985; Ming et al., 2021). Furthermore, along with a novel and interesting experience, minor problems may be overlooked (see, e.g., Norman, 2002, p. 41). Such reasons must be considered in testing phases to avoid biases affecting evaluations.

According to these results, the TIER model can be used in this kind of organized test process of XR-based technical instructions, and the analysis of results. This article was written together with Rebekah Rousi. The tasks were divided as follows. The author of this PhD dissertation conducted the empirical experiments and analysis of the results with the TIER model. Rousi participated in developing the related literature component of the article connected to user-centred design. She was also an active co-writer.

5 SCENARIO-BASED APPROACH WITH THE TIER MODEL COMPARING DIFFERENT TYPES OF XR

The articles of this doctoral research focused on a holistic view, encompassing the common features across various types of XR. While variety can be seen as a strength when it comes to tools to choose from, there is also the matter that certain tools perform better than others when utilized in specific contexts. Thus, this chapter focuses on selecting the appropriate type or types of XR to deliver technical instructions for specific needs. Therefore, this chapter focuses on the unique features of types of XR.

When starting to use XR to mediate technical instructions, achieving the best combination of benefits and minimized challenges will depend on selecting the most suitable solution. Different types of XR are functional in different tasks. Some forms of XR are actively developed, while others remain stagnant and marginal. That means no applications are suitable for every type of XR in set use cases. Here, scenario-based design (e.g., Carroll 1999) is used in combination with the TIER model to demonstrate the predicted outcomes of certain assemblages of factors. The purpose was to compare the possibilities and challenges of different types of XR in the use of some typical situations where technical instructions would be needed. This chapter aims to create a form of assistance to aid decision-making when choosing the most suitable type or types of XR for specific user purposes.

Below, four scenarios are used in the matrix tables of the TIER model to illustrate how each type of XR is or could be, used to fulfil different needs of technical instructions. These scenarios are based on the possibilities and challenges of different types of XR rather than real applications. Scenarios are usually detailed stories of specific cases (e.g., Carroll 1999, p. 44). In this chapter, they are used on a general level and kept brief to make them as general as possible, more as a frame than an actual story. As such, they are suitable for a general-level situation in more contexts. When used in a design process of actual technical instructions with a combination of the TIER model, scenarios are recommended to be longer and detailed stories of specific use cases typical of the organization for which they are designed. The scenarios used in this chapter are listed in Table 5.

Table 5. Example scenarios.

Scenario	Explanation
1. Preparing to start using the technical device.	Familiarization with the instructions, maintenance, and preparations needed before starting to use the device.
2. Malfunction of the device.	How to identify the cause of the problem, and how to solve it.
3. User safety	How to address user safety and secure user privacy.
4. Privacy and security	What issues relate to the use of this type of XR

Scenarios 1–3 were chosen because they are relatively typical use situations for technical instructions, irrespective of the type of technical device, the user group, and the country where the device is used. Scenario 4 is chosen because of the pervasive nature of XR. Next, I will introduce each type of XR and illustrate it with these four scenarios. The sub-Chapter starts with details of the scenarios in actual reality (not part of XR) to establish a reference point for the scenarios.

In Table 6, the example scenarios are introduced based on *actual reality*. When the technical instructions include only elements of actual reality, without virtual elements, this typically means, for example, face-to-face instructions or paper manuals. Paper manuals are still widely used, and many people are accustomed to reading them, although they are, depending on the context, rather unpopular and often not read (Novick & Ward, 2006). Regular video instructions can be included under the umbrella of actual reality in this context since they do not match the definition of XR as an interactive, 3D, and context-related environment (see Chapter 1.1.2).

The methods of actual reality are functional in all the example scenarios but not ideal. For example, face-to-face instructions can be given when a new employee is inducted into an organization. However, they are not economical, and it is up to the instructor to remember to convey everything relevant. Furthermore, it is up to the person instructed to remember what is taught.

Paper manuals are of assistance when they are utilized. They require understanding based on words and static pictures and cannot be situation-related, 3D, or interactive. However, they have the benefits of tradition and cost-effectiveness and can be taken anywhere. If a manual is lost or destroyed, printing another is easy, quick, and cheap.

Table 6. Scenarios with Actual Reality.

Reality	Finding
Preparations	Face-to-face instructions, printed manuals, and video instructions offer different ways to instruct diverse learners. <ul style="list-style-type: none"> • Instructions given face-to-face can include showing the user how to perform a task independently to minimize mistakes. A face-to-face introduction is often used to introduce a new employee to the organization and their job responsibilities. However, it is the instructor's responsibility to remember to explain each step. Furthermore, having someone providing face-to-face instructions for long periods and many users is not economically viable. Face-to-face instructions might be used in a new employee induction. • Printed manuals should include each step, but they may sometimes be difficult to understand with just pictures to complement the words (e.g., Chu et al., 2020). • Video instructions offer a combination of both by showing how to do something, from one angle at least, step by step.
Malfunction	Learning to manage a malfunction in actual reality risks maltreatment of the real device and the user's safety. Furthermore, actual reality instruction types require that the user remembers how to recognize risky situations and either how to act in such a case or where to find instructions for that.
Safety	Safety training in real situations can be expensive and dangerous. Printed instructions can hinder users from obtaining a clear idea of the task, and practising safety procedures may be risky with a real machine. If the instructions are given face-to-face, there is a risk that something is forgotten, or misunderstood.
Privacy and security	There is no significant risk to privacy and security in any case of face-to-face, printed, or video-based technical instructions.

Video instructions can show how step-by-step, like face-to-face instruction, and offer easily re-usable instructions like paper manuals. However, they are never context-related and need equipment to watch them. Training in situations of malfunction or safety can create risks to both devices and users if conducted in actual reality. With privacy and security, there are no remarkable risks. In Table 7, the example scenarios are introduced when using VR.

Table 7. Scenarios with Virtual Reality

VR	Finding
Preparations	VR-based instructions can be seen as a combination of the methods of actual reality, as they can offer step-by-step instructions by showing what to do, which can be done in video-based instructions. However, VR offers more freedom for the users to choose the angle of viewing that is relevant to them. A limitation is that VR is usually experienced through VR glasses, which makes the interaction with actual reality slower, as the user needs to keep putting the glasses on and off when using VR-based instructions to complete a task in actual reality. Methods of actual reality do not have this limitation.
Malfunction	In the case of malfunction in VR, the malfunction needs to be first noticed. The information on how to solve the malfunction should be searched. In this, the methods of actual reality and VR are the same. Here, VR is not ideal because of the need to switch back and forth between actual and virtual environments to learn and conduct the required activities. However, in VR, the instructions to solve the malfunction can be more informative than methods of actual reality.
Safety	VR is an excellent environment for efficient safety training in different tasks. It offers a fully immersive environment, thus enabling safe training in situations that would be dangerous to train in a real environment. It is also an economically sound alternative. From this perspective VR has an advantage over methods of actual reality.
Privacy and security	VR equipment must collect precise information about the user's position, movements, and eye gaze to create a fully immersive atmosphere and situate the virtual elements correctly. The amount of data collected is large. Furthermore, as the user experiences a fully immersive environment, it is impossible to be aware of privacy-sensitive objects or events occurring in actual reality that the device may record.

VR-based instructions are ideal for training and practising new tasks because they offer cost-effective and safe environments in which to practice difficult and dangerous tasks, or tasks that would be expensive to practice with real artefacts. When the task requires interacting with real objects, VR becomes less useful. It can still be used but requires moving back and forth between VR and actual reality. Compared to paper manuals, VR requires expensive equipment and is slower than checking paper manuals, but it can assist by offering more ways to support understanding. With privacy and security, the risks are remarkable because VR must continually track the user and the environment to function; however, being an immersive technology, the user cannot see what is tracked. Furthermore, the sensation of being in the virtual environment tends to make the user forget the real

environment and its details, as the focus is on virtual elements. In Table 8, the scenarios are introduced with AR-based instructions.

Table 8. Scenarios with Augmented Reality.

AR	Finding
Preparations	AR is ideal for tasks that demand seeing instructions while completing the task because informative and versatile instructions can be given via head-mounted displays (HMD). This releases the user's hands to complete the task without blocking the view of the real environment. They are also remarkably more informative than printed manuals. The instructional elements can even point at each part of an assembly task and show how and where a part needs to be put. AR-based instructions offer a combination of the best features of face-to-face and video instructions. They are situation-related, like face-to-face instructions, but economic, as similarly to video instructions, AR-based instructions do not require another person to be present.
Malfunction	In the case of malfunction, AR-based solutions have similar benefits to preparations. In addition, AR-based instructions can in these cases also help recognize and locate the reason for the malfunction.
Safety	In safety-related situations, AR has another benefit compared to most other types of instruction: the ability to alert users of hazardous situations in their environment. The user can be alerted by, for example, blinking icons with a combination of voice and haptic elements to ensure that the user's attention is drawn to the situation.
Privacy and security	Similar types of privacy and security issues to VR are involved. However, in AR, the virtual elements often need to interact with actual elements, requiring even more precise environmental mapping than VR. However, AR users can see their actual environment and, therefore, at least cover such privacy-sensitive elements and events they notice while using the equipment.

AR is a flexible and versatile type of XR and is, therefore, suitable for many tasks and purposes. It offers both a view of actual reality and interactive, situation-related virtual elements. AR always requires particular hardware, such as cameras and displays, yet it can be mediated via a smartphone or tablet in its most basic form. Head-mounted displays are becoming more cost-effective due to increased interest in AR and the associated technological advances. Therefore, it seems that AR has an advantage over other types of MR. With the presence of privacy and security risks, AR has the same issues as VR. However, the user can see actual

reality, so to some extent can bear privacy in mind when using AR equipment. In Table 9, the scenarios are introduced with AV.

Table 9. Scenarios with Augmented Virtuality

AV	Finding
Preparations	AV is superior to VR in tasks related to preparations or malfunctions since the virtual world could include instructions, and the real element could be a live video of the actions to be conducted with a real device in cases of preparation or malfunction. AV has been used in, for example, training surgical tasks and guiding in real surgical operations.
Malfunction	
Safety	AV has been applied in hazard recognition training with promising results. However, when a dangerous situation is imminent, AV may not be the best solution to search for information since the actions need to be conducted in a real environment instead of the virtual one, which is the basis of AV.
Privacy and security	The privacy and security challenges of AV are similar to AR. However, the user's ability to notice possible privacy-risk events in the environment is more limited than in AR, as there are fewer elements of actual reality to be seen.

AV is functional in several tasks, perhaps especially for collaboration purposes. However, such purposes were not included in the example scenarios used in this research, and AV is not ideal for the chosen scenarios. AV can be used, for example, for training purposes. It has been used with positive results in hazard recognition. There are also several applications of AV in different fields and tasks. However, it has not attracted nearly as much interest as AR or VR, and therefore the number of applications is significantly lower, which limits the opportunities to use AV. Based on the level of immersion, the risks to privacy and security are greater than in AR but less severe than in VR. In Table 10, DR is introduced to those scenarios.

Table 10. Scenarios with Diminished Reality

Diminished Reality	Finding
Preparations	DR is not very useful in tasks like preparations or to address malfunctions. However, had the view been blocked for some reason, DR could, in theory, be used to remove the obstacle. Perhaps it could be used to remove the unnecessary parts from view, thus providing an unobstructed view of objects required at the time. Combined with AR, it could then assist by showing what actions are necessary to complete the task. For training to repair a machine, DR could diminish outer
Malfunction	

Diminished Reality	Finding
	layers so that the necessary vision could be ensured to practice or at least imagine what would be necessary to complete the task.
Safety	In a situation requiring quick action, DR equipment could show the user which machine is blocked by diminishing all the objects between the user and the machine to immediately reveal what is happening and what issues demand a quick reaction.
Privacy and security	Privacy and security risks are similar to AR.

DR has not been applied to situations of the scenarios, which might expose the above suggestions to criticism. However, there are several better-suited applications of DR. It could also be used with AR so that while some objects of actual reality are deleted, some virtual objects are added. However, the number of applications for DR is relatively low, and its development is slow. It is, accordingly, rarely a reasonable option on its own. The example scenarios with mediated reality are introduced in Table 11.

Table 11. Scenarios with Mediated Reality

Mediated Reality	Finding
Preparations	Mediated reality would be excellent in this kind of task, as it offers multiple possibilities. It could augment instructions on top of the user's view like AR, diminish unnecessary objects like DR, and also highlight, enlarge or reduce objects, and slow or accelerate the instructions.
Malfunction	Mediated reality would enable embedded instructions for instructing actions to solve malfunction cases with endless opportunities to alter the view. For example, enlarging and slowing down the view of the area where the repairing actions would be needed with instructional guidance would allow the user to see the operation in detail as many times as needed.
Safety	Mediated reality would be a solution well-suited for safety-related tasks. It could, for example, alert the user of the situation, highlight the machine that is jammed, show a view of its insides where the blockage is, show the instructions, and tone down unnecessary parts of the machine.
Privacy and security	Privacy and security issues are similar to those of AR.

As the broadest type of MR, mediated reality could be the most adjustable and flexible mediator for multiple situations if its development had been active.

However, the trending focus on seeing MR as a whole can offer similar opportunities if that focus leads to applying many types of MR combined. The example scenarios are introduced with virtualized reality in Table 12.

Table 12. Scenarios with Virtualized Reality

Virtualized Reality	Finding
Preparations	For these kinds of tasks, virtualized reality works no better than VR. Both are immersive, and the user has to keep switching between virtual(ized) and real views. Without virtually added elements, virtualized reality is probably less capable for this task. However, in training, virtualized reality is useful. The real environments can be realistically transformed into virtualized reality so that users can practice real situations in real environments. It would then be possible to practice in realistic scenarios.
Malfunction	
Safety	In theory, virtualized reality could be used in situations necessitating safety-related actions since virtualized reality works in real-time. Suppose this technology was enabled in the work environment when a situation occurs. In that case, it could start rolling on the HMDs, showing the situation and, with virtually added elements, how to resolve it.
Privacy and security	Privacy and security issues with virtualized reality can be seen as greater than with VR. As the actual reality is virtualized, the required mapping is related to the kind of mapping that AR needs, but as an immersive technology, the user's ability to be aware of the actual environment is non-existent.

Virtualized reality, like VR, is suitable for training tasks because it offers a more realistic view. But, the definition does not include artificial guiding elements as VR does. This is a restriction because virtual elements can be used in multiple ways to improve finding information in technical instructions and understanding it. Virtualized reality is applied actively in several fields but is mostly considered part of VR. However, there is a difference if the actual reality is virtualized and the virtual environment is created from artificial elements.

The scenarios reveal radical differences in the amount of development and applications between the types of XR. Usually, it is enough to introduce a continuum with MR divided into AR and AV, excluding the rare types of MR. However, it is important to realize that there are other types as well, and they are more or less used, if not under different terminology. The terminology that is applied in research is important. If and when the research focuses on certain types in certain contexts, terminology can indicate not only the artefacts or systems to which it refers, but the use, cultural and professional context within which it is

referred. Terminology can even be seen as part of user-centricity (Isohella & Nissilä, 2015).

Various types of XR offer several benefits and are suitable for different tasks. Using more than one type of XR at any one time is one way to utilize the best features of each. For example, VR has been utilized in prototyping and evaluating AR content (Burova et al., 2020). However, no matter how promising the possibilities offered by a certain type of XR are, the amount of interest in the solution plays a crucial role as that determines whether the technology and enough applications are available to support the desired purposes.

When planning XR-based technical instructions, it is appropriate to know what type of possibilities exist to make decisions. In Table 13, the usefulness of different types of XR in different example scenarios is formulated based on earlier descriptions of how each type of XR is or could be, utilized in different tasks. The actual reality is used as a reference point in this summary table, marked therefore as Neutral. The chart with scenarios 1–3 here reports “very un-useful,” “not very useful,” “neutral,” “useful,” and “very useful”.

Table 13. Summary

	Preparations	Malfunction	Safety	Privacy and security
Actual reality	Neutral	Neutral	Neutral	Neutral
Diminished reality	Not very useful	Not very useful	Not very useful	Dangerous
Augmented reality	Very useful	Very useful	Very useful	Dangerous
Mediated reality	Very useful	Very useful	Very useful	Dangerous
Augmented virtuality	Useful	Useful	Useful	Dangerous
Virtualized reality	Not very useful	Not very useful	Useful	Very dangerous
Virtual reality	Not very useful	Not very useful	Useful	Very dangerous

Table 13 illustrates how the volume of privacy and security risks associated with XR grows with the degree of immersion. The chart to evaluate the danger ranges from neutral (actual reality) to dangerous and very dangerous. The structure reflects the fact that no type of XR is less dangerous than actual reality. High privacy and security risks will always be associated with XR, but the possibility of the user influencing those risks varies based on how much that user engages with reality.

These scenarios introduce one way of applying the TIER model in designing XR-based technical instructions in the phase of choosing the type(s) of XR relevant to that specific case. Actual use scenarios would then be put in the matrix tables of the TIER model similarly to what was introduced and compared with the features from different types of XR, which should help decide which type of XR would be most beneficial and carry the least risk.

It seems that different types of XR are increasingly used in conjunction to one another. Such combinations multiply the possibilities XR can offer when delivering technical instructions. One antecedent of choice rests in the number of technological solutions and applications available for the type of XR in question. In terms of availability, AR and VR are far ahead. However, the current trend of combining different types in technological solutions and applications has the potential to generate very flexible and versatile solutions.

6 DISCUSSION

This research introduced the affordance model of Technical Instructions in Extended Reality (TIER). The TIER model is an outcome of an attempt to illuminate one emerging technology area, XR, as a medium to deliver technical instructions. Fast technological changes require flexible and applicable methods for identifying and defining the consequences that the use of new technology brings to the field of technical communication. The TIER model facilitates an organized and holistic design process capable of application to a range of XR-based technical instructions.

The model increases current knowledge by serving as a framework for enhancing awareness concerning the facets and stages of data management. It provides a structured approach to investigation, offering an ontological reference for designers, technical communicators, and scholars. This reference supports a thorough exploration of the various phases and components, as well as their implications on the utilization and efficacy of specific forms of XR in the mediation of technical instruction. This perspective is informed by prior works such as Guizzardi and Halpin (2008), Polhill and Salt (2017), and Wand and Weber (1990). As a result, the TIER model connects the central features of technical instructions and XR to enable the undertaking an organized, continuous and comparable design and test process of XR-based technical instructions.

This research defines the core of technical communication as collecting, managing, and transferring knowledge from professionals to users, as justified in Chapter 1.1.1., Technical communication as a research field. Therefore, the approach is user-centred. In the context of this research, technical instructions are seen as well-functioning if they include all the necessary features required for filling the main purpose of technical instructions. Markel (2012, p. 3) reports that main purpose is guiding users to operate technical devices.

In the TIER model, these features are the affordances of accessing, finding, understanding, and relying on. The core of XR is derived from its definition of an interactive, context-related, and three-dimensional environment that includes virtual elements either in combination with the actual environment or with aiming to be completely immersive. Therefore, in the service of technical communication, XR offers the possibility to provide interactive, context-related, and three-dimensional instructions with a combination of multiple elements, such as videos, text, audio, and haptic elements. This research has analysed how XR handles data when used as a medium to deliver technical instructions in sequential phases: collection, processing, storage, transfer, combining, and presentation.

However, XR requires certain equipment, and also carries risks. The current research highlights the privacy and security risks (Gugenheimer et al., 2022), as they have not previously been specific risks in the field of technical communication. The pervasive nature of emerging technologies brings these challenges to the field. XR requires constant mapping of the user's positioning, orientation, eye gaze stream, and everything in their environment to situate the virtual elements in the right place at the right time. Therefore, using XR makes considerable volumes of sensitive data vulnerable to misuse and attacks. Research on and discussion of these new challenges are in high demand in the technical communication field. The current PhD study thus addresses an important research gap.

This research project was conducted in three phases. In the first phase, central features of well-functioning technical instructions and XR were identified. In the second phase, these features were combined to create the TIER model. In the third phase, the selected, user-centred aspects of the TIER model were piloted in three experiments focused on the testing process of XR-based technical instructions. The results were reported in five articles included in this doctoral dissertation.

The three research questions of this study were as follows:

- (R1) What are the features of well-functioning technical instructions when delivered via XR?
- (R2) How can the benefits and challenges that the use of extended reality brings to the context of technical instructions be identified and analysed?
- (R3) How can the TIER model be used in the testing process of XR-based technical instructions to identify preconceptions and/or error handling?

With regard to R1, the features under scrutiny in this research pertain to those of well-functioning technical instructions. Well-functioning technical instructions are seen here as those that guide users to operate technical devices as intended. Therefore, features of well-functioning XR-based technical instructions are identified as possible functionalities, namely the affordances of *accessing*, *finding*, *understanding*, and *relying on* (Rantakokko & Nuopponen, 2019). Well-functioning technical instructions also ensure users can access the instructions. Following accessing, the relevant information is retrievable among the masses of other information. When the relevant information is found, the user must be able to understand it. Finally, the user must be able to rely on the instructions and information at all times; otherwise, there is the risk that they will not utilize the instructions even when needed.

In this research, technical instructions are seen holistically, focusing on the common features of very different types of instructions instead of differences. Differences between various types of technical instruction are often considered so substantial that a holistic view can appear impossible. This research uses the concept of affordances to find common ground to enable a holistic model for XR-based technical instructions. Its holistic aspect means the TIER model can be used in specific use cases by inserting the desired outcomes in the matrix tables and following the iterative, user-centred design process. While there are a plethora of studies suggesting practical solutions for XR-based instructions, there is a lack of models for organizing the design process and focusing on how the practical outcomes introduced in various studies may support desired functionalities and how the risks of XR as an emerging technology and design flaws can be minimized.

Finding a way to identify and analyse the benefits and challenges of using XR as a medium for technical instructions required two steps, which is the aspect on which R2 focuses. The first step was to determine the possibilities and challenges brought by XR to the process of designing technical instructions. The task was approached by identifying the phases of XR data handling. The resulting phases are collection, processing, storage, transfer, combining, and presentation. The second step entailed combining those XR data handling phases with the affordances of technical instructions in the form of the TIER model. That finding facilitated a comparison of how the phases of XR data handling affect the affordances of technical instructions. Therefore, the solution suggested by this research is a model that enables the discovery of effects in the situations needed: comparing central features of one or more types of XR and applying them to the type of instructions that must be designed.

Finally, the third research question approached the practical level by seeking how the TIER model can be applied. Reflecting the user-centred nature of the TIER model, the task relied on three experimental studies focused on the influence of human actors on the process of designing technical instructions. These experiments served as a pilot test for the TIER model. They targeted a method to identify user preconceptions, avoid biases, conduct error management of the testing process of XR-based technical instructions, and the overall process of the organized testing phase with the TIER model. In Chapter 5, the TIER model was also applied to identify the benefits and challenges of different types of XR in selected use scenarios. These are examples of using selected parts of the TIER model for different needs.

6.1 Research contributions

The contributions that have emerged during this research are multidisciplinary by nature. They extend across bodies of knowledge within the realms of technical communication, XR, human-computer interaction, information systems, ergonomics, design, information architecture and design, and psychology to name some.

XR offers a plethora of possibilities for technical instructions, which is why this medium is increasingly used. These possibilities include safe and economic training, more effective learning and work processes and better hazard recognition (Doshi et al., 2017; Benbelkacem et al., 2013; Tang et al., 2003; Tzimas et al., 2019; Albert et al., 2014). While new technologies, such as XR, offer fascinating possibilities, they also bring multiple challenges with them, such as privacy and security issues. (Acquisti & Stutzman, 2014; De Guzman et al., 2019; McPherson et al., 2015; Adams et al., 2018) Furthermore, new skills and new ways to organize the information delivered and collected are in demand. There is a need to be aware of the main features in order to avoid unnecessary mistakes and waste of resources.

This research makes three contributions: the TIER model; highlighting the importance of privacy and security issues in the field of technical communication; and terminological work on XR. In Figure 25, these contributions are introduced in relation to the structure of this research.

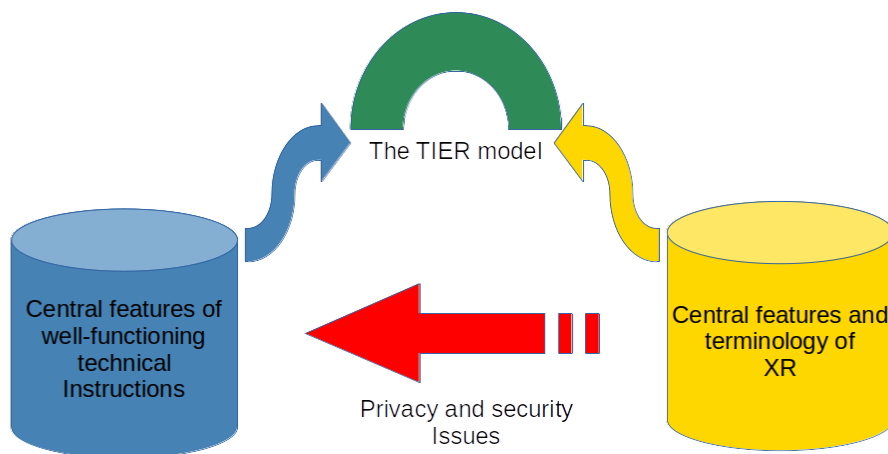


Figure 25. The core contributions of this research have emerged from identifying the central features of both XR and technical instructions, clarifying and updating the terminology of XR, and

highlighting the issues of privacy and security. Together these contributions form the TIER model, which rests at the center of this research.

Given that the goal of this research was to increase understanding of XR as a medium of technical instructions, the main contribution of this research project is the TIER model. Identifying and analysing the central elements of well-functioning technical instructions and XR while combining these features in the TIER model extends the knowledge of technical communication professionals. That was achieved via a systematic approach for analysing and comparing different types of XR and their benefits and deficits concerning the desired affordances of technical instructions. The TIER model does not require a deep understanding of new technology, which is important because technological advancements are constant. An increasingly larger portion of the work in many fields requires awareness of new possibilities and the challenges that those technologies bring to the fore. The TIER model meets this need.

The TIER model offers a frame of reference for a tool to support the organized design process of XR-based technical instructions. It combines two topics of interest: technical instructions and XR, with a new, holistic point of view. The holistic approach enables the focus to be placed on the common features of different technical instructions and different types of XR instead of differences. This approach makes it possible to bring the core of those topics together for use in various development processes implementing XR-based technical instructions. Accordingly, it is possible to use the model as a tool for designing different forms of technical instructions delivered via one or more types of XR. The TIER model encourages the user to choose the best combination of solutions for each task with the same organized approach, balancing the possibilities and challenges.

This method is designed to be flexible and applicable in different circumstances. It can be implemented, when designing different types of XR-based technical instructions. It is also useful for different audiences and various technical devices, considering the rapid development in the field (see, e.g., Wang et al., 2019).

This research recognizes the dual nature of theory and practice in the field of technical communication. Additionally, the central topics in the field, such as knowledge sharing and user-centricity, are intrinsic to this work. Consequently, the theory-based TIER model is designed primarily for applied use yet is flexible enough to be utilized in research. Both approaches are introduced in this doctoral dissertation.

This research respects the special knowledge of professionals who design technical instructions. They are expected to know the relevant information related to the technical devices in question and how to communicate to create successful technical instructions for the devices. Those instructions should include adequate information on relevant laws, ethical principles, design principles, organizational practices, target user groups, and use contexts. (Anderson, 2013, pp. 4–8). Despite the extensive knowledge of professionals who design technical instructions, more information about new technologies, such as XR, is needed (Tham et al. 2018, p. 178). This need can be approached by combining knowledge of XR (Rantakokko, 2022a) with the features of well-functioning technical instructions (Rantakokko & Nuopponen, 2019) via a model that enables organised and comparable analyses (Rantakokko, 2022b). These analyses occur at each phase of an iterative and user-centred design process of XR-based technical instructions (Rantakokko, submitted; Rantakokko & Rousi, submitted).

The second contribution highlights the importance of privacy and security issues in XR-based technical instructions, which is a new concern in technical communication, as shown by the scant research published on this topic. New technologies have changed the dynamics between designers, users, and instructions, making recognising and researching issues such as privacy crucial. This research brings these issues and potential ways of addressing these issues into focus.

The TIER model can be used to identify and minimize privacy and security risks when designing XR-based technical instructions. Different types of XR used in various contexts cause different risks relating to the user, the organization, and passers-by. It is important to consider, for example, if and when the data collected by the XR equipment should be transferred, where it should be stored, and what kind of security measures should be taken. However, it is important to recognize that the risks are not limited to data gathering. The TIER model enables consideration of issues emerging during other phases, such as transfer and data storage.

There is a potential additional benefit of the TIER model related to the cross-profession cooperation in organizations. Such cooperation is included in the remit of a technical communication specialist. When adopting an emerging technology, the decision-making and the extent to which technical communication experts can influence decisions varies. From this perspective, the TIER model can be seen as an organizational tool that could support decision-making and cross-professional cooperation.

While hardware has not yet been developed specifically for the purposes of technical communication, there is an ongoing interest in developing applications for XR-based solutions (see, e.g., Dey et al., 2018; Nebeling et al., 2018; Heinonen, 2023). Developing applications requires an interest in practical solutions in technical instructions; financial and time-related resources; and access to XR technology. However, not everyone has such opportunities and resources. Therefore, there is a need for methods and tools to be used in the design process with new technology for operators with limited resources that can advance development and learning at a deep level.

The third contribution of this research is the terminological work. A new version of the reality-virtuality continuum is suggested, one considering recent advances in technology, while types that are no longer prevalent are excluded. Furthermore, an umbrella concept (XR) of MR and VR is added to the continuum, justifying its definition. This continuum helps designers analyse how appropriate different types of XR chosen as a medium to deliver technical instructions are for various applications. Furthermore, it is important to update the terminology of XR for theoretical reasons and to avoid misunderstandings caused by unstable terminology.

6.2 Limitations and future research

There are some limitations to this research. The main result of this research, the TIER model, suggests a holistic approach, and thus far, it has been tested and used in only a few different cases with a limited number of participants. The COVID-19 situation played a role in the design of experiments. The pre-XR test was conducted remotely to avoid face-to-face contact, limiting data-gathering methods. The two tests with XR equipment were carried out with a limited number of participants (four each). Therefore, the results of the tests are not generalizable, and the results need to be validated with larger follow-up tests to enable comparison with differences based on background variables, different starting sets, and others.

Furthermore, the tests lacked continuity as there were no actual technical instructions in the development process. Therefore, the results of the tests were not followed by iterative phases of improving the instructions before the next test period, as would be the recommended case in a normal design process. More tests and use cases would be required to identify whether and to which degree the TIER model needs further development.

Certain choices must be made when developing a theoretical model. In this case, those choices included the affordances approach for technical instructions and the process for XR. When choices are made, limitations follow. A certain approach only frames certain viewpoints. For example, this research and the TIER model focus strictly on XR from the viewpoint of technical instructions, thus excluding other applications of this technology and medium.

The knowledge of professionals in technical communication is included in this research through previous research. The model is introduced to practitioners by publishing Articles 2 and 3 in a journal focused on technical communication practice rather than scientific, technical communication scholarship. However, technical communication professionals have not so far been involved in the development process of the TIER model. As Andersen and Hackos (2018) highlight, research and practice should draw from each other for mutual benefit (p. 2). They reported that the steps to improve theory usefulness for practitioners include inviting organizations to participate in studies (p. 5). Now that the TIER model is pilot tested with promising results, it could be incorporated in a wider process of designing actual XR-based technical instructions, thus involving professionals in the field.

The main methodological limitation is the lack of a complete test process of the TIER model. However, the results of the limited tests were promising. Furthermore, a pilot test with an economical and easily replicable method is a reasonable way to ensure a preliminary estimation of the model's functionality before investing more resources into a larger test process. The results, however, need to be validated with a complete test process in the future.

As the holistic approach to XR-based technical instructions is a relatively new topic, one challenge was the lack of previous research on the precise topic under study. There was no existing theoretical model and very little information on best practices to appraise. There is plenty of previous research concerning XR (see, e.g., Bruno & Muzzupappa, 2010; Nebeling et al., 2018; Papagiannis, 2017; Graig, 2013; Aukstakalnis, 2017), technical instructions (see, e.g., Baker, 2007; Carradini et al., 2020; Buchner et al., 2022; Vanneste et al., 2020; Loorbach et al., 2006), and even both (see, e.g., Tang et al., 2003; De Amicis et al., 2017; Benbelkacem et al., 2013; Tzimas et al., 2019; Heinonen, 2023), but a broader perspective is so far missing. There is additionally an obvious lack of attention that has been placed on privacy and security of new technologies in the field of technical communication, and particularly technical instructions. Therefore, previous research is required from different viewpoints regarding this research. As theoretical understanding is

evolving continuously over time, soon new understanding will arise that reflects the datedness of current understandings.

Due to the fact that this research had adopted a holistic view on two separate topics of technical instructions and XR, there was no possibility of including either topic comprehensively. Compromises have to be made, which is also a limitation. For example, privacy and security issues are not examined to the extent merited by their increasing importance. Instead, that must remain a future research avenue.

There are several possible directions future research could take. The TIER model could benefit from a checklist that would feature the general advantages and deficits of each type of XR (see e.g., De Paiva Guimaraes and Martins, 2014). This cannot be all-encompassing, but possibly the illustration of basic features may assist in choosing the right type of XR for certain tasks. The TIER model could also be suitable for technologies other than XR, such as applications of Internet of Things (IoT). This would naturally require more research. In addition, the issues of privacy and security desperately need more research from multiple viewpoints, such as issues of usability and emotional connotations of privacy and security (see, e.g., Rousi, 2022; Rousi, Vakkuri, Alanen & Rantakokko, 2023).

XR-based technical instructions should be studied further from a multidisciplinary perspective by combining aspects from different fields, such as psychology, ergonomics, cognitive science, and pedagogy. XR is not an isolated field but is rather developed in connection to other technologies, such as AI. Therefore, foreseeing future development and applications should also include aspects of other technologies developed and used in relation to XR, such as the Internet of Bodies (IoB). For example, there is a trending interest in combination of XR and AI (see, e.g., Hirzle et al., 2023; Nkulu-Ily, 2023; Qayyum et al., 2022)

Furthermore, the designers of technical instructions need more tools. For example, a model assisting with the design of XR-based technical instructions focusing on the content and changes that the new medium requires in relation to information presentation would be an important addition to the toolbox of technical communication professionals. In comparison, the TIER model focuses on the design process of mediated delivery rather than the content of the XR-based technical instructions.

As a potential limitation, the complete TIER model may seem rather abstract for a practitioner, as it has an aspect for organizational interests. Therefore, there is a need to continue the development with practitioners, to ensure that the TIER model is sufficiently practical to be properly utilized in a design process of XR-based technical instructions.

6.3 Conclusions

This research aimed to expand knowledge of XR as a medium to deliver technical instructions. This topic is driven by changes brought about by new technologies, such as IoT, AI, and XR. These changes influence working life and society as a whole. Therefore, there is a need for a flexible model for managing change and knowledge. In this research, the specific focus was on XR and its influence on the field of technical communication. The outcome of the current research is a theoretical model combining central features of technical instructions and XR in a way that enables an organized, continuous and comparable design and test process of XR-based technical instructions. The model is holistic and goes beyond its current purpose, as it anticipates the consequences of rapid change influenced by technological developments.

Technical instructions have existed since the invention of technical devices and will be needed in the future. The forms in which instructions are delivered depend on the development of technological solutions and the needs that technical instructions are designed to fulfil. Besides XR-based technical instructions, the development of technical instructions has moved in several other directions in recent years. Those include aspects of gamification, different ways to create digitally animated and interactive instructions (see, e.g., Letmathe, 2021), utilizing robotics (see, e.g., Matuszek et al., 2013), and other new technologies.

While technical communication professionals are mastering the development of technical instructions, new technologies require changes in the design of instructions. XR applications, for instance, require less text and different structuring than printed manuals. Instructions employing MR cannot include large objects that would block the view of the real environment. Moreover, constantly moving and blinking objects would be disturbing. It is now especially important to test the technical instructions accompanying new technology because of the many changes in how instructions can be presented to users.

In the service of technical communication, XR combines several unique benefits. For example, it can resemble face-to-face teaching in several ways, such as via virtual avatars, and the ability to interact with both virtual and real objects. This enables a phase-by-phase display of tools and parts from which to choose, as well as how to operate with them in diverse scenarios. Elements can also be added to XR applications in addition to visual objects, such as tactile and haptic elements. For example, vibration can catch the user's attention in hazardous situations. Today XR can offer a low-cost and risk-free environment for training in new tasks.

It has become more commonly used in industrial environments in recent years. (see, e.g., Krauß et al., 2022).

Technological challenges have been obstacles to the widespread distribution of XR. Yet, as solutions become less expensive and problems such as delays or eye fatigue grow less troublesome, the technology is starting to reach maturity. More equipment and more applications are available, thus enabling multiple-uses.

The results of this research project have indicated several possibilities and challenges in using XR as a mediator of technical instructions. These are related to both the nature of XR and how it constantly collects data from the users and their surroundings. This characteristic brings possibilities for interactive, real-time, and three-dimensional technical instructions that can assist with training and using technical devices in multiple ways. Among the challenges, this same feature means that a massive amount of data becomes collected, processed, transferred, stored, making it vulnerable to accidental data leaks and attacks.

There is a myriad of technological solutions of which to remain abreast, with limited time and resources to do so. Technical communication professionals acknowledge the need to gain more information on technological solutions, which should be offered in an easily usable way that does not consume too many resources. The TIER model is a usable tool that does not require the user to thoroughly understand XR. It also offers an organized way to test the designed XR-based technical instructions and to improve them in an iterative manner.

During this research, the question of what is and what is not included in the profession of a technical communication specialist arose. While it is a debate on its own and beyond the purview of this research, there is still a relation to it based on the nature of the TIER model. As mentioned above, the TIER model could be a useful organizational, cross-professional tool supporting decision-making, and its use could extend beyond certain professions. Whether increasing the cross-professional cooperation is welcomed could be debatable. However, the profession of a technical communication specialist already includes cross-professional aspects and cooperation with other experts. The holistic approach of this research and the TIER model encourages rather than constrains extending cross-professional cooperation. As emerging technologies bring new challenges and possibilities to every field, there may be a growth in the required expertise to balance utilizing the possibilities and minimizing the risks.

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Appendices

Appendix 1

Features of XR

Author(s), title and number of references in Google Scholar	Introduction of the book / paper, the publisher and its H Index according to Scimago Journal & Country Rank (SJR). H Index quantifies scientific productivity and scientific impact.
Papagiannis (2017): Augmented human: how technology is shaping the new reality. Number of references: 63	Focused on the possibilities of AR in her book. Took a look in not only visual AR, but also tactile, audio and olfactory. Her aspect was "seeing the world anew" with this fascinating technology. Published in O-Reilly Media. Not listed in SJR.
Graig (2013): Understanding augmented reality: concepts and applications. Number of references: 469.	Focused on hardware and software of AR systems, introducing in detail the major components of both. Also took a look in interaction and applications in AR. Published in Morgan Kaufman. Not listed in SJR.
Aukstakalnis (2017): Practical augmented reality: a guide to the technologies, applications, and human factors for AR and VR. Number of references: 151.	Introduced technologies and applications of both AR and VR from many aspects, such as virtual spaces and human senses. Took a look at the many fields that these technologies are used in, such as education and engineering. Published in Addison-Wesley. Not listed in SJR.
Tham et al (2018): Understanding Virtual Reality: Presence, Embodiment, and Professional Practice. Number of references: 34.	Focused on the functions, features and uses of Google Cardboard, Google Daydream View, and HTC Vive. Aimed to showcase current or potential deployments with modified heuristics. According to the results, VR immersion can provide students with a deeper understanding of the content to be learnt, and an initial vision of the project and profession. Published in IEEE Transactions on Professional Communication. H Index 42.

Mediating instructions

Author(s), title and number of references in Google Scholar	Introduction of the book / paper, the publisher and its H Index according to Scimago Journal & Country Rank (SJR). H Index quantifies scientific productivity and scientific impact.
Zauner et al (2003): Authoring of a mixed reality assembly instructor for hierarchical structures. Number of references: 183.	Introduced a MR application, Authoring Wizard, for step-by-step assembly of furnitures for assembly experts. It allowed users to be authors as well. It was also able to select components, and define and store all types of elements. Published in The Second IEEE and ACM International Symposium on Mixed and Augmented Reality, Proceedings. Not listed in SJR.
Doshi et al (2017): Use of projector based augmented reality to improve manual spot-welding precision and accuracy for automotive manufacturing. Number of references: 81.	Focused on a projector-based spatial augmented reality (SAR) and its use in manual spot-welding operations. SAR was used to highlight spot-weld locations on vehicle panels. The results indicated better accuracy and increase in precision with AR system than without it. Published in The International Journal of Advanced Manufacturing Technology. H Index 112.

Author(s), title and number of references in Google Scholar	Introduction of the book / paper, the publisher and its H Index according to Scimago Journal & Country Rank (SJR). H Index quantifies scientific productivity and scientific impact.
Benbelkacem et al (2013): Augmented reality for photovoltaic pumping systems maintenance tasks. Number of references: 42.	Proposed an AR platform with a tracking system for maintenance tasks to stabilize water supply for remote regions and deserts. The results indicate e.g. flexibility and time saving. Published in <i>Renewable Energy</i> . H Index 174.
De Amicis et al (2017): Augmented Reality for virtual user manual. Number of references: 25.	Proposed an AR-based method to support the assembly of components, creating a virtual user manual in an AR environment. The manual recognized and identified the components, and combined VR procedure with typical AR process in motion tracking. Published in <i>International Journal on Interactive Design and Manufacturing (IJIDeM)</i> . H Index 20.
Tang et al (2003): Comparative effectiveness of augmented reality in object assembly. Number of references: 587.	Conducted a study to test the relative effectiveness of AR instructions in an assembly task. The results suggest that AR can improve task performance and relieve mental workload on assembly tasks, being more effective instructional medium. Published in <i>Chi '03 Proceedings of the SIGCHI Conference on Human Factors in Computing Systems</i> . Not listed in SJR.
Tzimas et al (2019): Machine tool setup instructions in the smart factory using augmented reality: a system construction perspective. Number of references: 15.	Created an AR demonstrator highlighting the feasibility of low-cost, efficient and user friendly AR applications for industrial guidance and training. Focused on technical aspects and developed an application that aimed at "supporting the turning center operator in clamping rotational parts". Published in <i>International Journal on Interactive Design and Manufacturing (IJIDeM)</i> . H Index 20.
Yew et al (2016): Towards a griddable distributed manufacturing system with augmented reality interfaces. Number of references: 65.	Described a framework for computer-integrated AR manufacturing system. It aims to improve the information perception of the different types of workers in a manufacturing facility, and to make interaction with manufacturing software natural and efficient. Published in <i>Robotics and Computer-Integrated Manufacturing</i> . H Index 84.

Evaluation

Author(s), title and number of references in Google Scholar	Introduction of the book / paper, the publisher and its H Index according to Scimago Journal & Country Rank (SJR). H Index quantifies scientific productivity and scientific impact.
Elia et al (2016): Evaluating the application of augmented reality devices in manufacturing from a process point of view: An AHP based model. Number of references: 81.	Developed an AHP model to quantitatively evaluate AR devices in manufacturing. The results suggest that reliability and agility are the most important features to an AR device. These features support information exchange during the maintenance task. Published in <i>Expert Systems with Applications</i> . H Index 184.
Arbeláez-Estrada and Osorio-Gómez (2013): Augmented Reality Application for Product Concepts Evaluation. Number of references: 20.	Proposed an AR application for Android mobile devices to help decision-making activities through the design process. The designer is able to get feedback of the user through their own mobile device and context, getting the user's visual experience, thus making evaluation process less subjective. Published in <i>Procedia Computer Science</i> . H Index 59.

Hazard recognition

Author(s), title and number of references in Google Scholar	Introduction of the book / paper, the publisher and its H Index according to Scimago Journal & Country Rank (SJR). H Index quantifies scientific productivity and scientific impact.
Albert et al (2014): Enhancing Construction Hazard Recognition with High-Fidelity Augmented Virtuality. Number of references: 133.	Developed Systems for Augmented Virtuality Environment Safety (SAVES) to help develop workers' hazard recognition skill in dynamic environments. The results indicated significant improvement in hazard recognition and communication, and potential benefits in occupational health and safety training. Published in Journal of Construction Engineering and Management – ASCE. H Index 105.

Usability

Author(s), title and number of references in Google Scholar	Introduction of the book / paper, the publisher and its H Index according to Scimago Journal & Country Rank (SJR). H Index quantifies scientific productivity and scientific impact.
Olsson (2012): User Expectations and Experiences of Mobile Augmented Reality Services. Number of references: 34.	Aimed to understand both user expectations and the actual UX of the first-generation mobile augmented reality applications. Studied expected experiences, and both satisfying and unsatisfying actual experiences. Published in Tampere University of Technology. Not listed in SJR.
Dey et al (2018): A Systematic Review of 10 Years of Augmented Reality Usability Studies: 2005 to 2014. Number of references: 140.	Reviewed and classified, based on their application areas, 291 papers with 369 individual user studies. Aimed to “present the broad landscape of user-based AR research, and to provide a high-level view of how that landscape has changed”. Published in Frontiers in Robotics and AI. H Index 21.

Training

Author(s), title and number of references in Google Scholar	Introduction of the book / paper, the publisher and its H Index according to Scimago Journal & Country Rank (SJR). H Index quantifies scientific productivity and scientific impact.
Albert et al (2014): Enhancing Construction Hazard Recognition with High-Fidelity Augmented Virtuality. Number of references: 133.	Developed Systems for Augmented Virtuality Environment Safety (SAVES) to help develop workers' hazard recognition skill in dynamic environments. The results indicated significant improvement in hazard recognition and communication, and potential benefits in occupational health and safety training. Published in Journal of Construction Engineering and Management – ASCE. H Index 105.

Effects

Author(s), title and number of references in Google Scholar	Introduction of the book / paper, the publisher and its H Index according to Scimago Journal & Country Rank (SJR). H Index quantifies scientific productivity and scientific impact.
Miller et al (2019): Social interaction in augmented reality. Number of references: 47.	Conducted three studies in order to test the social psychological effects of AR. Noticed that virtual humans in AR can socially influence performance. Interaction between two AR users with one of them occluded by virtual content did not lead to differences, but AR users compared to the users not wearing an AR headsets tended to have lower social presence and IOS scores. Published in PloS ONE. H Index 300.

Design process

Author(s), title and number of references in Google Scholar	Introduction of the book / paper, the publisher and its H Index according to Scimago Journal & Country Rank (SJR). H Index quantifies scientific productivity and scientific impact.
Bruno and Muzzupappa (2010): Product interface design: A participatory approach based on virtual reality. Number of references: 122.	Evaluated a participatory design approach where VR was both a tool to evaluate the usability of the virtual product interface, and a communication channel enabling users to directly participate in the design process as co-designers. Published in International Journal of Human Computer Studies. H Index 116.
Nebeling et al (2018): ProtoAR: Rapid Physical-Digital Prototyping of Mobile Augmented Reality Applications. Number of references: 25.	Introduced an easier and less time-consuming way to create content in AR, ProtoAR. It enables the physical prototyping with paper and Play-Doh, which is then generated into virtual content with ProtoAR tools. Published in CHI '18 Proceedings of the 2018 CHI conference on Human Factors in Computing Systems. Not listed in SJR.

Interaction

Author(s), title and number of references in Google Scholar	Introduction of the book / paper, the publisher and its H Index according to Scimago Journal & Country Rank (SJR). H Index quantifies scientific productivity and scientific impact.
Piumsomboon et al (2017): Exploring natural eye-gaze-based interaction for immersive virtual reality. Number of references: 89.	Explored strengths and weaknesses of three eye-gaze based interaction techniques inspired by natural eye movements: Duo-Reticles, Radial Pursuit and Nod and Roll. Found positive results in e.g. preference, satisfaction and fatigue. Published in 2017 IEEE Symposium on 3D User Interfaces, 3DUI 2017 – Proceedings. H Index 9.

Symbols

Author(s), title and number of references in Google Scholar	Introduction of the book / paper, the publisher and its H Index according to Scimago Journal & Country Rank (SJR). H Index quantifies scientific productivity and scientific impact.
Scurati et al (2018): Converting maintenance actions into standard symbols for Augmented Reality applications in Industry 4.0. Number of references: 50.	Proposed to create and adopt a vocabulary of graphical 2D symbols to be used in AR to represent maintenance instructions. The results indicate that this approach was simple and lowered mental load of the users, and that 2D symbols have value for the frequent general purpose tasks, while 3D are better for very complex customized operations. Published in Computers in Industry. H Index 93.

Appendix 2

Risks

Author(s)	Introduction
Acquisti et al (2014): Face recognition and privacy in the age of augmented reality. Number of references: 81.	Conducted studies to combine online-data with face recognition. Succeeded to identify 10% of a dating site profiles based on Facebook, and 33% of people walking by the campus based on social network data, cloud computing and a facial photography. Found also a significant amount of online information of the identified persons, such as sexual orientation or Social Security numbers. Published in Journal of Privacy and Confidentiality. Not listed on SJR.
De Guzman et al (2019): Security and Privacy Approaches in Mixed Reality: A Literature Survey. Number of references: 31.	Focused on recent research concerning security and privacy risks and protection approaches of MR and VR. Found that only a few (1,42% of 2016) are discussing the impacts, or presenting security and privacy approaches applied to, or using XR. Published in ACM Computing Surveys. H Index 143.
Happa et al (2019): Cyber Security Threats and Challenges in Collaborative Mixed-Reality. Number of references: 8.	Investigated the cyber-security challenges of CMR systems in MR. Focused on network architectures facilitating CMR, its vulnerabilities, and the social, monetary, psychological and other harms they may result from exploits. Presented an abstraction-based reasoning framework to identify potential attack vectors. Published in Frontiers in ICT. H Index 12.
McPherson et al (2015): No Escape From Reality: Security and Privacy of Augmented Reality Browsers. Number of references: 21.	Analyzed the functional requirements of AR browsers, and investigated the security architecture of Junaio, Layar and Wikitude. Identified multiple architectural flaws that caused security and privacy risks. Proposed short-term solution suggestions. Published in WWW 2015 – Proceedings of the 24 th International Conference on World Wide Web. H Index 29.
Rauschnabel et al (2018): Antecedents to the adoption of augmented reality smart glasses: A closer look at privacy risks. Number of references: 94.	Developed a theoretical model to asses AR smart glasses (ARSG). Noticed that utilitarian, hedonic, and symbolic benefits drive consumers' reactions to ARSG, and that ARSG's threat of privacy for bystanders can influence users' decision-making rather than privacy threat of their own. Published in Journal of Business Research. H Index 179.

Solution suggestions

Author(s)	Introduction
Ahn et al (2018): Adaptive fog-based output security for augmented reality. Number of references: 18.	Proposed a method for generating adaptive policies to secure visual output in AR systems using deep reinforcement learning. In their approach, a local fog node runs training simulations to learn an appropriate policy for filtering potentially malicious or distracting content of an application. Published in VR/AR Network 2018 – Proceedings of the 2018 Morning Workshop on Virtual Reality and Augmented Reality Network, Part of SIGCOMM 2018. Not listed in SJR.
Lebeck et al (2017): Securing augmented reality output. Number of references: 40.	Focused on security and privacy issues especially concerning the data presentation phase. Developed Arya, an AR based platform architecture that focuses on output security. Arya succeeded to address many output security issues without making reasonable

Author(s)	Introduction
	performance impossible. Published in 2017 IEEE Symposium on Security and Privacy. Not listed in SJR.
Ferreira et al (2007): Security and privacy in a middleware for large scale mobile and pervasive augmented reality. Number of references: 6.	Proposed, tested and analysed a security and privacy architecture for a previously proposed middleware architecture for mobile and pervasive large scale AR games. Also described security and privacy issues and the solution suggestions. Published in 2007 15th International Conference on Software, Telecommunications and Computer Networks. H Index 6.
Reilly et al (2014): prototyping usable privacy and security for mixed reality collaborative environments. Number of references: 13.	Presented SecSpace, a software toolkit for usable privacy and security research for MR collaboration. SecSpace “permits privacy-related actions in either physical or virtual space to generate effects simultaneously in both spaces”. Published in 2007 15th International Conference on Software, Telecommunications and Computer Networks. H Index 6.
Roesner et al (2014): Security and privacy for augmented reality systems. Number of references: 156.	Focused on security and privacy challenges with AR technologies especially concerning data collection and data presentation. Suggested solutions for some of these. Published in Communications of the ACM. H Index 203.

Bystanders' privacy

Author(s)	Introduction
Denning et al (2014): In situ with bystanders of augmented reality glasses: perspectives on recording and privacy-mediating technologies. Number of references: 146.	Focused on the bystanders of AR glasses with field studies and interviews. The results suggest that a significant part of the bystanders (11 of 31) do not pay attention that someone nearby is wearing AR glasses. Almost every participant reacted indifferently (16) or negatively (12) to the idea of being recorded by an AR device. Published in CHI'14: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. Not listed in SJR.

Privacy policies

Author(s)	Introduction
Adams et al (2018): Ethics emerging: the story of privacy and security perceptions in virtual reality. Number of references: 16.	Focused on privacy and security perceptions in VR from the aspect of privacy policies and ethics. Noticed that the users and the developers are mainly concerned about risks of well-being, security and privacy. Also found significant deficiencies in the privacy policies. Published in Proceedings of the Fourteenth Symposium on Usable Privacy and Security. Not listed in SJR.

Increasing safety

Author(s)	Introduction
Lukosch et al (2015): Providing Information on the Spot: Using Augmented Reality for Situational Awareness in the Security Domain. Number of references: 49.	Developed an AR system to support information exchange in the security domain, especially concerning situational awareness within the expert teams that need relevant and up-to-date information for quick decision-making. The results suggest that AR system was suitable for the tasks, and improved collaboration of the teams. Published in Computer Supported Cooperative Work. H Index 63.

Hirsto, H., M. Enell-Nilsson & N. Keng (toim.) 2019. *Työelämän viestintä II, Arbetslivskommunikation II, Workplace Communication II, Kommunikation im Berufsleben II. VAKKI-symposium XXXIX 7.–8.2.2019. VAKKI Publications 10. Vaasa, (53–66)*

Laajennetun todellisuuden tarjoumat tekniselle viestinnälle – kohti teoreettista mallia

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This article is part of a research project that explores the use of eXtended Reality (XR) technology and applications to convey technical guidance instead of traditional printed manuals. In the article we present the first stage of forming a theoretical model to explore the phenomenon. The model is based on the concept of affordance and the various points of views of it form four levels of the model: level of rules, level of designed affordances, level of potential affordances and level of affordances as completed actions. These levels will be utilized to scrutinize the affordances extended reality applications offer for technical instructions. The first affordances reported for in this article are those of availability, findability, understandability and reliability of technical instructions based on an analysis of a set of guides and standards for technical instructions.

Avainsanat: affordanssi, laajennettu todellisuus, tarjouma, tekninen ohje

1 Johdanto

Tämä artikkeli liittyy tutkimukseen, jonka tavoitteena on selvittää, millaisia mahdollisuuksia laajennetun todellisuuden käyttö antaa tuotteisiin liittyvien ohjeistusten laatimiselle. Jotta tästä ilmiökentästä saataisiin yhtenäinen kuva, olemme luoneet alustavan mallin, joka tulee toimimaan tutkimuksen teoreettisena runkona.

Muodostettava malli pohjautuu tarjouman eli affordanssin (*affordance*) käsitteeseen (esim. Gibson 1979; Treem & Leonardi 2012; Lanamäki, Thapa & Stendal 2016). Sen avulla voidaan selittää ja tarkastella teoreettisesti sosiaalisten ja teknologisten elementtien vuorovaikutusta eli ihmisten ja erilaisten artefaktien välisiä suhteita (Lanamäki ym. 2016), jollaisesta myös tässä tutkimuksessa on kyse.

Tässä artikkelissa käsittelemme mallin muodostamisen ensimmäistä vaihetta. Seuraavassa käymme ensin läpi laajennetun todellisuuden käsitettä sekä sen hyödyntämistä teknisessä viestinnässä. Sen jälkeen taustoitamme tarjouman käsitettä ja kuvaamme ja havainnollistamme tarjoumamallin ensimmäistä versiota.

2 Laajennettu todellisuus

Laajennetussa todellisuudessa (*eXtended Reality, XR*) on kyse siitä, että aistittavaa todellisuutta laajennetaan keinotekoisilla, tietokoneella tehdyillä elementeillä. Laajennetun todellisuuden sovelluksia käytetään erilaisten laitteiden välityksellä, esim.

älypuhelimet, tabletit ja VR/MR-lasit. Tällaisen sovelluksen käyttäjä voi muun muassa saada näkyviin näkymätöntä tai kätkeytä tai seikkailla täysin keinotekoisessa ympäristössä. Teknisessä viestinnässä laajennetun todellisuuden avulla voidaan esimerkiksi koneen korjaajalle tarjota tilannekohtaiset korjausohjeet erillisten lasien avulla, jolloin niiden linssille heijastuva ohje osoittaa suoraan korjattavasta kohteesta tarvittavat toimenpiteet vaihe vaiheelta ja kädet vapautuvat suorittamaan työtehtävää.

Laajennettu todellisuus on kattokäsite, joka kattaa **yhdistetyn todellisuuden** ja **virtuaalitodellisuuden**. Yhdistetty todellisuus (*Mixed Reality, MR*) muodostuu yhdistämällä virtuaalisia elementtejä eriasteisesti todellisuuteen. Virtuaalitodellisuus (*Virtual Reality, VR*) puolestaan rakentuu kokonaan keinotekoisista, digitaalisista elementeistä. Yhdistetyn todellisuuden tunnetuin taso on **lisätty todellisuus** (*Augmented Reality, AR*), joka nousi suuren yleisön tietouteen etenkin Pokémon Go -pelin myötä. Laajennetun todellisuuden käsitteet ja niihin viittaavat termit ovat vielä osin vakiintumattomia, erityisesti suomenkielisten vastineiden osalta.

Azuman (1997) määritelmä lisätylle todellisuudelle on käyttökelpoinen laajemmin yhdistetylle todellisuudellekin siinä merkityksessä, mikä tämän tutkimuksen kannalta on olennaista. Hänen mukaansa kyse on todellista ja virtuaalista yhdistävästä, reaaliaikaisesti interaktiivisesta ja kolmiulotteisena rekisteröidystä kokonaisuudesta. Reaaliaikaisuus, interaktiivisuus ja kolmiulotteisuus ovat ominaisia myös virtuaalitodellisuudelle, mutta siinä varsinainen todellisuus pyritään sulkemaan mahdollisimman tehokkaasti kokemuksen ulkopuolelle.

3 Laajennettu todellisuus teknisen viestinnän palveluksessa

Tässä tutkimuksessa laajennettua todellisuutta tutkitaan **teknisen viestinnän** kontekstissa. Salmelan ja Isohellan (2018: 54) mukaan teknisen viestinnän voisi määritellä teknisen informaation välittämiseksi tiedon omaavalta tietoa tarvitsevalle. Markel (2012: 3) pohtii teknisen viestinnän keskeistä olemusta siten, että julkaisumuodosta riippumatta tekninen ohjeistus on tarkoitettu auttamaan ihmisiä tehtävän oppimisessa ja suorittamisessa. Tässä artikkelissa keskitytään pääasiassa tekniseen tuotteeseen liittyvään työ- ja käyttöohjeeseen, josta käytämme nimitystä *tekninen ohje*. Teknistä ohjetta voidaan tarkastella valmistajan, ohjeen laatijan ja ohjeen käyttäjän näkökannoista. Lisäksi kyse on heidän suhteestaan tuotteeseen, sen käyttämiseen ohjeistavaan tekniseen ohjeeseen sekä ohjeen välittämiseksi käytettyyn mediaan.

Laajennettua todellisuutta on alettu tutkia viime vuosina enenevässä määrin. Laajennetun todellisuuden ja teknisen viestinnän yhdistävä tutkimus on kuitenkin vasta alkuvaiheessa, ja sitä tehdään usein yritysten omina kehityshankkeina, joista ei välttämättä yrityksen ulkopuolella saada tietoa. Saatavilla oleva tutkimus keskittyy tavallisimmin tietyn laajennetun todellisuuden osa-alueen arviointiin jonkin yksittäisen työtehtävän osalta,

kuten esimerkiksi Doshin, Smithin, Thomasin ja Bourasin (2017) tutkimuksessa, jossa tarkasteltiin projektoripohjaista lisättyä todellisuutta pistehitsauksessa. Tällaisissa tutkimuksissa on havaittu selviä hyötyjä laajennetun todellisuuden käytöstä; esimerkiksi virheiden vähentymistä ja täsmällisyyden lisääntymistä (emt.), kognitiivisen kuormituksen vähenemistä sekä tarkkuuden ja tehokkuuden lisääntymistä (Uva, Gattullo, Manghisi, Spagnulo, Cascella & Fiorentino 2017), vaaratilanteiden tunnistamisen paranemista (Albert, Hallowell, Kleiner, Chen & Goldparvar-Fard 2014) ja tehtävän oppimisen ja siitä suoriutumisen nopeutumista (Hoedt, Claves, Van Landeghem & Cottyn 2017).

4 Tarjouman käsite

Tutkimuksen kohteena oleva tutkimuskenttä on hyvin moniulotteinen. Siksi lähdimme rakentamaan mallia, jonka avulla olisi mahdollista tuoda yhteen teoriaa ja todellista ilmiötä mahdollisuuksineen ja rajoituksineen. Näin voitaisiin lisätä kokonaisvaltaista ymmärrystä ja luoda kattava kokonaiskuva laajennetun todellisuuden käytöstä teknisessä viestinnässä (vrt. Hughes 1997: 325; Morgan ja Morrison 1999: 7–8). Pyrkimyksenä on mahdollistaa laajennetun todellisuuden tarkastelu kokonaisuutena yksittäisten osaluokkien sijaan, sillä esimerkiksi lisätty todellisuus ja virtuaalitodellisuus tuovat erityyppisiä mahdollisuuksia kokonaiskuvaan. Malli mahdollistaa myös laajennettua todellisuutta hyödyntävien teknisten ohjeiden vertaamisen muihin julkaisumuotoihin.

Lähtökohdaksi tähän otimme **tarjouman** käsitteen, jonka Lanamäki ym. (2016: 125) toteavat nousseen ydinkäsitteeksi tietojärjestelmien tutkimuksessa. Myös muun muassa Treem ja Leonardi. (2012: 146) tuovat esiin tarjouman käsitteen käyttökelpoisuuden uusien teknologioiden ja sosiaalisten käytäntöjen suhteiden tutkimisessa. Majchrzak, Markus ja Wareham (2016: 272) toteavat teknologian tarjoumien ja rajoitteiden sopivan erityisen hyvin teorian rakentamiseen tieto- ja viestintätekniikan (ICT) käytöstä.

Tarjouman käsite pohjautuu James J. Gibsonin (1979) ajatuksiin eläinten tavasta hahmottaa ympäristöään käyttötarkoitusten kautta. Hänen mukaansa eläin ei niinkään ensisijaisesti hahmota esimerkiksi kiveä, vaan ennemminkin sarjan toimintoja, joita kivi mahdollistaa. Nämä esineen mahdollistamat toiminnallisuudet hän nimesi tarjoumiksi (*affordances*). Myöhemmässä tutkimuksessa hänen käsitettään on kritisoitu liian epämääräiseksi ja sitä on pyritty tarkentamaan. Gibsonin käsitettä on kritisoitu erityisesti siitä, että tämä ei ole tarkentanut tarjoumaan liittyvän suhteen (esim. eläimen ja kiven suhde) laatua tai kestoa. Gibsonille (1979) tarjoumat vain yksinkertaisesti ovat olemassa. Tarjouma käsitetään usein kuitenkin esineen ja toimijan suhteeksi (esim. Volkoff & Strong 2013: 822; Lanamäki ym. 2016: 127). Jotta tarjoumalla olisi merkitystä, on myös oltava joku, jonka on mahdollista se toteuttaa (Volkoff ym. 2013: 822). Lanamäki ym. (2016: 127–128) ovat löytäneet aiemmasta tutkimuksesta neljä erilaista näkökantaa (*stance*) tarjoumaan: **kanoninen tarjouma, suunniteltu tarjouma, potentiaaliset**

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tarjoumat ja suoritettut toiminnot tarjoumina. Kaikki nämä näkökannat vastaavat Gibsonin ajatuksia, mutta eroavat painotuksiltaan. Lanamäki ym. (2016) suosittelevat, että tarkastelussa pidättäydyttäisiin kulloinkin vain yhdessä näkökannassa sekaannusten välttämiseksi. Omassa mallissamme kuitenkin otamme ne kaikki käyttöön tarjouman **tasoina** soveltaen. Tämä ratkaisu on tehty siksi, että voisimme tutkimuksen eri vaiheissa tarkastella ilmiötä kokonaisvaltaisesti eri toimijoiden ja vaiheiden näkökulmasta. Eli tämä näkökulman vaihdos tuo mukanaan myös näkökannan vaihdoksen.

Kanonisen tarjouman ontologisena perustana nähdään esineluokan suhde sosiokulttuurisiin käytäntöihin (esimerkiksi *tuolit ovat istumista varten*) (emt. 129). Tästä näkökannasta katsottuna tutkija voi selvittää esimerkiksi niitä sosiokulttuurisia prosesseja, joiden myötä tarjoumat ovat alun perin saaneet kanonisen muotonsa eli miten niistä on tullut yleisesti hyväksytyjä. Silloin, kun nämä tarjoumat ovat käsitteen tasolla olemassa ennen artefaktin suunnittelua ja toimintaa, analyysin päätehtäväksi tulee selvittää, käyttäytyvätkö tutkimuksen kohteet "onnistuneesti" eli tarjoumat toteutuvat vai "epäonnistuneesti" eli tarjoumat jäävät toteutumatta. Kanonisia tarjoumia ei voi todistaa vääräksi eli esim. tuoleista ei voi väittää, että niillä ei voi istua. Joku yksittäinen tuoli voi olla istumakelvoton, mutta ei voi sanoa, että tuolit yleensä eivät ole istumista varten. (Emt. 136)

Suunnittelun tarjouman perustana on suunnittelijan, esineen ja kuvitellun tai todellisen käyttäjän suhde (esimerkiksi *suunnittelin tämän esineen sinulle tietynlaista käyttöä varten*). Suunnittelijat sisällyttävät tuotteeseen erilaisia tarjoumia, jolloin näistä tarjoumista poikkeamiset voitaisiin nähdä ”väärinä tarjoumina”. (Emt. 130) Suunnittelun tarjouman näkökannasta voi tarkastella, kuinka suunnittelijat sisällyttävät tarjoumia tuotteen ominaisuuksiin ja kuinka heidän tarkoituksensa tulee sovitettua käyttöön (emt. 136).

Mahdollisissa tarjoumissa puolestaan on kyse esineen ja sen todellisen käyttäjän välisestä suhteesta eli sellaisista toiminnoista, joita hän sillä suorittaa (esimerkiksi *käytin tätä esinettä siihen tehtävään, mihin se oli tarkoitettu*). Tästä näkökulmasta käyttö voi olla jotain muutakin kuin mihin artefakti on suunniteltu. (Emt. 131) Mahdollisten tarjoumien näkökannasta tutkijat voivat selvittää prosessia, jossa tarjoumat on havaittu ja toteutuvat, ja kuinka monilukuiset tarjoumat syntyvät. Suurin osa Lanamäen ym. (2016: 136) tarkastelemista järjestelmätieteen tutkimuksista kuului tähän näkökantaan.

Neljäntenä näkökantana Lanamäki ym. (2016: 133) erottavat tarjouman ymmärtämisen sosiaalisten käytänteiden mukaisesti **suoritetuiksi teoiksi**. Kyse on todellisen esineen ja todellisen käyttäjän suhteeseen tietyssä tilanteessa (esimeriksi *suoritin tehtävän yhden tai useamman esineen avulla*). Tämän näkökannan mukaan tarjouma on tarjouma vain silloin, kun sen tarjoama toiminta on toteutettu. (Shotter 1983: 27) Tästä näkökannasta voidaan

tarkastella sitä, kuinka tarjoumat ilmenevät toteutuneissa tilannesidonnaisissa toiminnoissa (*situated completed actions*) (Lanamäki ym. 2016: 136).

5 Tarjoumien kartoittaminen teknistä ohjetta varten

Tehtävänäimme on siis etsiä ne tarjoumat, joiden suhteen laajennetun todellisuuden avulla toteutettuja teknisiä ohjeita voidaan analysoida ja verrata muihin toteutusmuotoihin. Lähestymme asiaa tutkimuksen ensimmäisessä vaiheessa teknisestä ohjeesta käsin. Tällöin pitää erottaa itse teknisen ohjeen tarjouma eli sen perustehtävä ja eri julkaisumuotojen mahdollistamat tarjoumat. Lähtökohtaisesti teknisen ohjeen perustehtäväksi voidaan määritellä tuotteeseen liittyvän tiedon välittäminen tarvittavien toimintojen suorittamiseksi. Tällaisia toimintoja voivat olla esimerkiksi kokoonpano, tuotteeseen tutustuminen, käytön opettelu, käyttäminen, huoltotoimet, ongelmatilanteiden ratkaiseminen ja tuotteen turvallinen hävittäminen (SFS 2012; Tukes 2016). Tämä nähdään jatkossa siis perustehtäväksi, jonka toteutumisen muut tarjoumat mahdollistavat, mikäli ne konkretisoituvat toteutumisen tasolla. Tarvitaan siis kaiken kattavan perustehtävän lisäksi hienojakoisempi jaottelu tarjoumista, joiden suhteen erityyppisiä julkaisumuotoja voidaan vertailla.

Tätä artikkelia ja tutkimusvaihetta varten lähdimme luomaan jaottelua teknisen ohjeen tarjoumien löytämiseksi tarkastelemalla teknisiä ohjeita koskevia lakeja ja säädöksiä (EK 2014; Tukes 2016), standardeja (SFS 2012) ja ohjeistuksia (Bly 1998). Tarkastelemme tässä vaiheessa teknisen ohjeistuksen olemusta siis niitä koskevien erilaisten sääntöjen kautta. Perustavana ajatuksena on kanoninen käsitys teknisen ohjeen käsitteestä, jonka ilmentymien sisältöä ja olemusta määritellään siihen liittyvien sääntöjen avulla. Näin säännöissä yhdistyvät erilaiset sosiokulttuuriset käytännöt, tiedot ja aiempi kokemus, joiden pohjalta teknisiä ohjeita on pyritty ohjaamaan ja yhtenäistämään. Säännöt antavat siten kattavan kuvan siitä, mitä teknisestä ohjeesta tulee löytyä, jotta päästään mahdollisimman optimaaliseen tulokseen loppukäyttäjän kannalta.

Valituista aineistolähteistä etsittiin erilaisia sääntöjä, joita niissä ohjeistukselle asetetaan (esimerkiksi se, että käyttöohjeet on ylipäätään laadittava). Yhteensä löydettävissä oli noin 470 erillistä sääntöjen esiintymää, joista osa toistui useammassa lähteessä samanlaisena tai saman tyyppisenä. Lopulta erilaisia sääntöjä jäi jäljelle 114, kun samanlaiset tai saman tyyppiset ilmentymät oli yhdistelty. Lisäksi monilla säännöillä oli tarkennuksia (esimerkiksi se, kenen tai keiden vastuulla käyttöohjeen laatiminen on).

Seuraavassa vaiheessa yksittäisten sääntöjen läpikäynnillä etsittiin teemoja tai kategorioita, joihin ne voitaisiin edelleen jakaa. Jakoperusteeksi nousivat ne seikat, joiden turvaamiseksi säännöt on laadittu. Säännöillä turvattiin pääasiassa neljää asiaa: sitä, että tekninen ohje ja sen sisältämä tieto pystyttäisiin saavuttamaan, löytämään ohjeesta tarvittavat asiat ja ymmärtämään ne, sekä se, että ohjeeseen ja sen sisältämiin tietoihin

voitaisiin luottaa. Nämä tekniseen ohjeistukseen liitettävät ominaisuudet mahdollistavat sen, että ohje voi täyttää perustehtävänsä. Tämän perusteella muodostamme ensimmäiset tarjoumat: **saavutettavuus, löydettävyys, ymmärrettävyys ja luotettavuus.**

Tarjousmallin perusta on siis muodostettu teknisen ohjeen ja kanonisen tarjoumakäsitteen näkökannasta, mutta mukana ovat myös muut näkemykset, jotka rakentuvat ja tarkentuvat tutkimuksen edetessä. Seuraavassa tutkimusvaiheessa paneudutaan suunniteltujen tarjoumien näkökantaan, ja silloin malliin tulee yhdistymään voimakkaammin laajennettu todellisuus vaikutuksineen. Seuraavassa pohdimme näitä neljää aineistosta esiin nousutta tarjoumaehdokasta.

5.1 Saavutettavuus

Saavutettavuuden tarjouma nähdään tässä siten, että teknistä ohjetta on ylipäättään mahdollista päästä tarkastelemaan ja käyttämään. Saavuttamista turvaavat säännöt, joita aineistolähteistä löytyi 46, jakautuivat toisaalta itse ohjeen saavuttamiseen ja toisaalta tarvittavien tietojen saavuttamiseen. Ohjeen saavuttamiseen liittyviä sääntöjä löytyi aineistolähteistä 15 kappaletta, esimerkiksi:

- (1) Teknisten asiakirjojen laatiminen on valmistajan vastuulla (EK 2014; Tukes 2016)
- (2) Käyttäjää tulee muistuttaa käyttöohjeiden säilyttämisen tärkeydestä ja huolehtia siitä, että toimittajalta on saatavilla korvaavia kappaleita (SFS 2012)
- (3) Ohjeet on toimitettava tuotteen luovutuksen yhteydessä (Tukes 2016: Kuluttajansuojalaki)

Tarvittavan tiedon saavuttamista turvaavat säännöt (31 kpl) paneutuivat siihen, että ohje sisältää kaiken tarvittavan tiedon. Tällaisia sääntöjä siitä, mitä tietoja ohjeissa on oltava, olivat esimerkiksi:

- (4) Tuotteen yksilöinti (valmistuserätunnus, sarjanumero, nimi/tyyppi jne.) (Tukes 2016)
- (5) Tuotteen normaalia käyttöä koskevat tiedot (miten sitä on tarkoitus käyttää, normaali toiminta, symbolien ja merkintöjen tarkoitus, käyttöön liittyvät rajoitukset jne.) (Tukes 2016)
- (6) Huolto-ohjeet ja tieto siitä, mitkä toimet ovat sallittuja vain ammattilaisille (Tukes 2016)

Sääntöjen mukaan ohjelajiksi on valittava parhaiten tarkoitukseen soveltuva (SFS 2012). Saavutettavuutta mietittäessä esimerkiksi painettu paperiohje on periaatteessa saavutettavissa helposti kuljettamalla sitä vain mukana, kun taas muut ohjeformaatit vaativat tällä hetkellä aina jonkinlaisen teknologian, kuten tietokone, älypuhelin, tabletti tai VR- tai MR-lasit. Toisaalta jos työtä tehdään pääasiassa tietokoneella, voi sähköisessä formaatissa oleva ohje olla helpoimmin saavutettavissa. Tai jos työ vaatii pitkäaikaista keskittymistä ja molempien käsien käyttöä, voi parhaiten saavutettavissa oleva ohje olla laajennettua todellisuutta hyödyntävä, lasien kautta tarkasteltava ja esimerkiksi

äänikomennoin toimiva ohje. Olennaista on käyttäjäkeskeisyys (SFS 2012) eli pohditaan juuri tietyn tuotteen käyttäjiä ja heidän ominaisuuksiaan, tapojaan ja niitä käyttötilanteita, joissa he ohjetta todennäköisesti tarvitsevat. Sitä kautta voidaan lähteä luomaan juuri heille sopivaa ohjetta siinä julkaisumuodossa, jossa he parhaiten ohjeen saavuttavat. Toisinaan mielekästä on toimittaa ohje useammassa formaatissa erilaisia käyttäjiä ja käyttötilanteita varten.

Saavuttamisen tarjouma on olemassa heti, kun jonkinlainen ohje on tehty. Se ei kuitenkaan konkretisoidu, ellei ohjetta pyritä aktiivisesti tarjoamaan käyttäjälle. Ohje, joka tehdään, mutta jota ei julkaista, sisältää kyllä saavuttamisen mahdollisuuden, mutta silloin tuo mahdollisuus on tavalliselle käyttäjälle lähes olematon. Sen sijaan esimerkiksi tuotteen myynnin yhteydessä tuotepakkaukseen liitetty ohje on tuotteen luovutushetkellä saavutettavissa jokaiselle tuotteen ostajalle. Myöhempi saavutettavuus riippuu siitä, mitä ostaja tekee ohjeelle tuotteen saatuaan.

5.2 Löydettävyys

Löydettävyyden tarjouma tarkoittaa sitä, että käyttäjä pystyy paikallistamaan tarvitsemansa tiedon ohjeen sisältämän muun tiedon joukosta. Löydettävyyttä edistäviä sääntöjä (21 kpl) ovat esimerkiksi:

- (7) Jaottelu sopiviin osiin (SFS 2012)
- (8) Sivunumerointi (SFS 2012)
- (9) Sähköisissä tietovälineissä on hyödynnettävä dynaamisia navigointi- ja esittämiskeinoja (tähän sisältyi muun muassa navigointijärjestelmän rakenteesta, elementeistä, aiheisiin siirtymisestä ja ohjelman käytön opastuksesta ohjeistavia tarkennuksia) (SFS 2012)

Löydettävyyttä suunniteltaessa on otettava huomioon käyttäjien tottumukset. Aineistossa korostuu käyttäjän turvallisuuden merkitys, joten erityisesti siihen liittyvien asioiden tulisi olla helposti löydettävissä. Ongelmaksi voi kuitenkin muodostua se, että käyttäjä ei välttämättä lue ohjeita, vaikka kaikki tarvittava turvallisuuteen liittyvä tieto niissä asianmukaisesti olisikin. Novickin ja Wardin (2006: 5) tutkimuksessa ilmeni, että huomattava osa käyttäjistä ei lue ohjeita edes silloin, kun tehtävä on vaarassa jäädä suorittamatta epäonnistumisen vuoksi. Jopa luovuttaminen oli yli kolme kertaa tavallisempaa kuin painetun käyttöohjeen lukeminen. Oppenheimerin, Meyvisin ja Davidenkon (2009) mukaan ohjeet lukiessaankin huomattava osa lukijoista vain silmäilee ylimalkaisesti eikä huomaa kaikkia tärkeitä ohjeistuksia. Lisäksi ongelmaksi jää painetun ohjeen suhteen, että vaikka tieto olisi luettu, jää noudattaminen muistinvaraiseksi. Sen sijaan laajennettua todellisuutta hyödyntävät ohjeet esimerkiksi MR-lasien välityksellä mahdollistavat tarvittavien turvallisuuteen liittyvien ohjeiden esittämisen juuri oikeassa tilanteessa oikeaan aikaan. Laseihin voidaan esimerkiksi heijastaa tieto turvallisuustoimia

vaativista toimenpiteistä työympäristössä sillä hetkellä, kun niihin tulee reagoida, jolloin ohjeet ovat sekä saavutettavissa että löydettävissä juuri oikealla hetkellä.

Löydettävyyden tarjouma voi toteutua, jos tekninen ohje on laadittu, siihen on sisällytetty tarvittava tieto, ja ohje on saavutettu. Mitä paremmin ohjeessa on huomioitu löydettävyyttä tukeva rakenne, sen helpompaa käyttäjän on etsiä juuri oikea tieto ja sitä todennäköisemmin löytämisen tarjouma myös konkretisoituu.

5.3 Ymmärrettävyys

Ymmärrettävyyden tarjouman ajatuksena on tässä se, että käyttäjän saavuttamasta ohjeesta löydetty tieto olisi ilmaistu sillä tavoin, ettei se jää käyttäjälle epäselväksi. Aineistosta löytyi 32 ymmärrettävyyttä turvaaviksi säännöiksi tulkittavaa kohtaa, esimerkiksi:

- (10) Informaatio tulee mukauttaa kohderyhmän tietämykseen (SFS 2012)
- (11) Käyttöohjeet on annettava suomen ja ruotsin kielillä (Tukes 2016: Kielilaki)
- (12) ”Technicalesen” välttäminen eli vältetään jargonia, kliseitä, vanhanaikaisia fraaseja, monimutkaista kielenkäyttöä ym. (Bly 2008)

Tiedon ymmärrettävyyttä voidaan tarkastella muun muassa kognitiivisen kuormituksen kautta. Esimerkiksi Uvan ym. (2017) tutkimukset spatiaalista lisättyä todellisuutta (*Spatial Augmented Reality, SAR*) hyödyntävistä ohjeista verrattuna paperiohjeisiin älykkäässä valmistuksessa (*smart manufacturing*) osoittivat SAR:n muun muassa pienentävän kognitiivista kuormitusta ja vähentävän virheitä sekä hyötyjen olevan suuremmat monimutkaisissa tehtävissä kuin yksinkertaisissa. Jos siis esimerkiksi tarvitaan ohjetta jonkin yksinkertaisen tehtävän suorittamiseksi, paras ratkaisu voi hyvinkin olla perinteinen paperiohje tai verkossa helposti saatavilla oleva ohje. Jos taas tehtävä on monimutkainen ja etenkin jos se sisältää merkittäviä turvallisuusriskejä, voi toimivampi ratkaisu olla laajennettua todellisuutta hyödyntävä tilannekohtainen ohje.

Ymmärtämisen tarjouma on olemassa, kun ohje on laadittu, mutta se ei välttämättä konkretisoidu. Ohje voi esimerkiksi olla kirjoitettu kielellä, jota käyttäjä ei ymmärrä, tai tarvittava toimenpide on voitu kertoa niin vaikeaselkoisesti, että käyttäjä ei sen perusteella pysty käsittämään, mitä hänen tulisi tarkalleen ottaen tehdä.

5.4 Luotettavuus

Luotettavuus nähdään tässä siten, että sekä ohjeen sisältö että julkaisumuoto koetaan luotettaviksi. Ohjeilla on merkitystä myös itse tuotteeseen luottamisen rakentumisessa. Aineistosta löytyi 15 erilaista luotettavuutta vahvistaviksi säännöiksi luokiteltavaa kohtaa, esimerkiksi:

- (13) Teknisten asiakirjojen sisällöllä on pystyttävä osoittamaan, että tuote on sovellettavien vaatimusten mukainen (EK 2014)
- (14) Puutteellisen sisällön välttäminen; kerätään tarpeeksi tietoa, jotta väitteet voidaan tukea faktoilla rakentaen siten luottamusta (Bly 2008)
- (15) Merkinnät ja varoitukset on määritelty tuotekohtaisissa standardeissa (Tukes 2016)

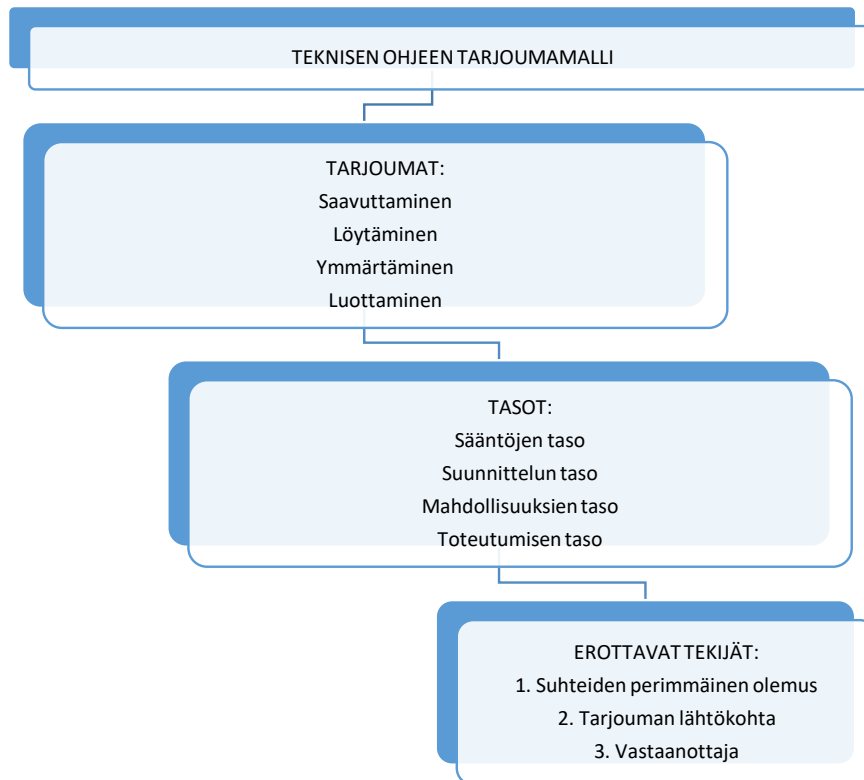
Ohjeformaatin valinnassa luotettavuuteen liittyvät kysymykset riippuvat paljolti käyttäjistä ja siitä, mitä he ovat tottuneet pitämään luotettavina tai mikä juuri heidän tyypillisessä käyttötilanteessaan on toiminnaltaan luotettava ohjeen julkaisumuoto. Esimerkiksi syrjäisessä sijainnissa ulkotiloissa tehtävässä työssä paperiohje saattaa nuhjaantua ja käydä vähitellen heikkolaatuiseksi luottavuudeltaan. Toisaalta sähköisiä apuvälineitä vaativat ohjeformaatit saattavat edellyttää esimerkiksi verkkoyhteyttä, joka ei välttämättä ole riittävän hyvin saavutettavissa kaikissa sijainneissa. Sähköisten apuvälineiden tarvittava lataaminenkaan ei välttämättä kaikkialla onnistu.

Luottamisen tarjouma on olemassa, kun ohje on laadittu, mutta jos ohje on esimerkiksi heikkolaatuinen ja kirjoitusasu ei vakuuta, voi luottamisen tarjouma jäädä toteutumatta. Käyttäjä ei välttämättä vakuutu siitä, että ohjeessa annetut neuvot ovat oikeasti järkeviä ja käyttökelpoisia.

6 Teknisen ohjeen tarjoumamalli

Edellä esitetyt tarjoumat – saavutettavuus, löydettävyys, ymmärrettävyys ja luotettavuus – nousivat esiin erilaisia ohjeita ja sääntöjä tarkastelemalla. Tällöin näkökannaksi valikoitui melko pitkälti kanoninen näkemys tarjoumista. Mallissa on kuitenkin tarkoitus tutkivaiheiden edetessä hyödyntää kaikkia Lanamäen ym. (2016) näkökantoja omina tasoinaan: sääntöjen (kanoninen) taso, suunnittelun taso, mahdollisuuksien taso ja toteutumisen taso. Eri tarkastelujen yhteydessä erilaiset tarjoumien tasot tulevat painottumaan eri tavoin. Kuviossa 1 on esiteltynä tarjoumamallin alustava rakenne.

Laajennetun todellisuuden tarjoumat tekniselle viestinnälle – kohti teoreettista mallia



Kuvio 1. Teknisen ohjeen tarjoumamalli

Jokainen näistä tasoista tuo mukanaan erilaisen tutkimusasetelman, sitoumuksen ja lähestymisen tutkimuksen kohteeseen. Tämä antaa mahdollisuuden tarkastella tutkimuskohdetta kokonaisvaltaisesti ja eri aikaperspektiiveillä, niin vakiintuneiden käytäntöjen, suunnitellun ja toteutuneen käytön sekä tulevaisuuden innovaatioiden hahmottelun näkökannastakin.

Malli koostuu tarjoumien ja niiden eri tasojen lisäksi myös tasoihin liittyvistä ja niitä erottavista tekijöistä, jotka perustuvat Lanamäen ym. (2016: 128) käyttämiin tarjoumakäsityksiä erotteleviin tekijöihin: minkä ja keiden välillä suhde vallitsee (*relational ontology*), tarjouman lähtökohta (*origin*), toimijuuden rooli (*role of agency*) eli kuka on toimija ja millä tavalla hän toimii, kuka nimeää ja kuka vastaanottaa tarjouman sekä milloin tarjouma päättyy ja missä se sijaitsee. Esimerkiksi kanonisen tarjouman osalta tarkastellaan suhdetta artefaktiluokan ja sosiaalisen käytänteen välillä, kun taas tarjouman lähtökohta viittaa sosiaalisten käytäntöjen synnyttämiin sääntöihin. Toimijuuden roolina toimii jaettu kulttuurinen ymmärrys (*shared cultural understanding*), nimeäjänä ovat ”kulttuuriset esi-isät” ja vastaanottajana kuka tahansa. Kanoninen tarjouma ei yleensä lakkaa olemasta vaan on aina läsnä. Se on universaali ja lajin tasolla (vs. yksilö). (Lanamäki ym. 2016: 128)

6.1 Sääntöjen taso

Mallin ensimmäinen taso, sääntöjen taso, pohjautuu kanoniseen näkökulmaan. Mallin tähän vaiheeseen valitut erottelevat tekijät (ks. kuvio 1) voidaan nähdä seuraavasti: 1. Suhteiden perimmäinen olemus on sääntöjen suhde teknisen ohjeen tarjoumaan. Tämä tarkoittaa sitä, että säännöt asettavat ohjeelle vaatimuksia, jotka johtavat saavutettavuuden, löydettävyyden, ymmärrettävyyden ja luotettavuuden tarjoumien sisällyttämiseen ohjeeseen ja edesauttavat näiden toteutumista. 2. Sääntöjen vastaanottajaksi ajatellaan teknisen ohjeen laatija, jonka toimintaa ohjataan säännöillä optimaalisen lopputuloksen turvaamiseksi ohjeen käyttäjälle. 3. Tarjouman lähtökohdan nähdään tällöin sijaitsevan säännöissä, jotka toimivat teknisen ohjeen laatimista ohjaavina. Esimerkiksi Kielilain mukaan Suomessa ohjeet on toimitettava suomeksi ja ruotsiksi, koska ne ovat maamme viralliset kielet. Koska ohjeen laadinta ja käyttäjälle tarjoaminen on valmistajan vastuulla (esim. EK 2014), tässä tasossa siinä mielessä on kyse valmistajan näkökannasta.

6.2 Suunnittelun taso

Mallin toinen taso on suunnittelun taso, jossa on kyseessä suunniteltujen tarjoumien (*designed affordances*) näkökanta. Siinä erottelevat tekijät nähdään seuraavasti: 1. Suhteiden perimmäisenä olemuksena on teknisen ohjeen laatijan, ohjeen ja kuvitellun käyttäjän suhde. 2. Vastaanottajana on kuviteltu käyttäjä. Lanamäen ym. (2016: 130) näkemyksissä suunnitellut tarjoumat voivat kohdistua myös todelliseen käyttäjään. Teknisessä ohjeistuksessa on tällä tasolla kyseessä kuitenkin ohjeiden laatijan käsitys käyttäjästä, eikä ohjeiden loppukäyttäjä ole vielä konkreettisesti mukana prosessissa. Joissakin tapauksissa ohje voidaan laatia jopa tiettyä yksittäistä käyttäjää varten esimerkiksi silloin, jos kyse on uuden työntekijän perehdyttämisestä työtehtäväänsä. Tällöinkin kyse on kuitenkin ohjeen laatijan ajatuksista kyseisestä käyttäjästä. 3. Tarjouman lähtökohdaksi käsitetään se, että suunnitteluprosessin kautta ohjeen laatija voi sisällyttää tarjoumia tekniseen ohjeeseen sen mukaan, mitä tarkoitusta ja millaista käyttöä varten hän ohjeen laatii. Hän voi siis esimerkiksi laatiessaan ohjetta laajennetun todellisuuden sovellukseen hyödyntää sanallisen selittämisen sijaan todelliseen työtilanteeseen kytkettyä, vaihe vaiheelta etenevää video-ohjeistusta saadakseen monimutkaisen tehtävän ohjeista mahdollisimman ymmärrettävät.

6.3 Mahdollisuuksien taso

Mahdollisten tarjoumien näkökantaan perustuvalla tasolla voidaan lähteä tarkastelemaan sitä, mitä tekninen ohje mahdollistaa todelliselle käyttäjälle. Erottelevat tekijät voidaan tulkita seuraavasti: 1. Suhteiden perimmäinen olemus on tässä teknisen ohjeen ja todellisen käyttäjän suhde, jolloin 2. vastaanottaja on siis todellinen käyttäjä. 3. Tarjouman lähtökohtana on se, että todellinen käyttäjä havaitsee ja vastaanottaa teknisen

ohjeen sisältämät tarjoumat. Niiden hyödyntäminen ja konkreettinen toteutuminen riippuu käyttäjän ominaisuuksista ja kontekstista. Ollaan siis tilanteessa, jossa sääntöjen puitteissa suunnitteluprosessin myötä kuviteltua käyttäjää varten ohjeeseen sisällytetyt tarjoumat ovat tarjolla todellisessa ohjeessa todelliselle käyttäjälle.

6.4 Toteutumisen taso

Neljännellä tasolla tutkitaan toteutumista eli sitä, miten nuo mahdollisuudet konkretisoituvat ja mitä todellinen ohje todellisessa tilanteessa todella tuotti tehtävän suorittamiseksi. Tämä taso vaatii siis aina todellisen, empiirisen kontekstin. Samalla se toimii ikään kuin tarkistuspisteenä sille, miten edellisten tasojen hyvät pyrkimykset ovat toteutuneet ja tarvitseeko jotakin muuttaa parhaan mahdollisen lopputuloksen saavuttamiseksi. Erottelevat tekijät ovat: 1. Tarjouman suhteiden perimmäinen olemus toteutumisen tasolla on edellisen tason lailla teknisen ohjeen ja todellisen käyttäjän suhde. 2. Tässäkin siis vastaanottaja on todellinen käyttäjä. 3. Tarjouman lähtökohta tarkoittaa tässä sitä, että tarjouma toteutui suoritettuna tekona tietyssä tilanteessa. Käyttäjä esimerkiksi etsi ja löysi tiettyä tehtävää varten tarvitsemansa tiedon, ymmärsi sen ja koki luotettavaksi, toimi ohjeen pohjalta ja sai tehtävän suoritetuksi.

7 Pohdinta

Laajennetun todellisuuden vaikutuksia teknisen ohjeen välittämisessä kuvaavan monitahoisen teoreettisen mallin pohjaksi valitsimme siis tarjouman käsitteen ja yhdistimme siihen liittyvät erilaiset näkökannat mallin eri tasoiksi: sääntöjen, suunnittelun, mahdollisuuksien ja toteutumisen tasot. Jokaista tarjoumaa tarkasteltiin näiden tasojen kautta ja tarkastelu syvenee tutkimuksen edetessä. Ensimmäisessä tutkimusvaiheessa teknisen ohjeistuksen sääntöjen tarkastelujen pohjalta teknisen ohjeen tarjoumiksi nousivat saavutettavuus, löydettävyys, ymmärrettävyys ja luotettavuus. Mallin jatkotyöstämisen ja soveltamisen yhteydessä nousee esiin todennäköisesti muita tarjoumia erityisesti laajennetun todellisuuden vaikutuksiin tarkemmin keskittyttäessä.

Tarjoumamallin tässä artikkelissa esitelty ensimmäinen vaihe painottuu siis voimakkaasti teknisiin ohjeisiin liittyviin sääntöihin laajennetun todellisuuden näkökulman jäädessä vielä taka-alalle. Koska tarkastelun kohteena kuitenkin ovat laajennetun todellisuuden vaikutukset teknisten ohjeiden välittämisessä, mallin perustaksi on tärkeää ottaa teknisen ohjeen näkökulma. Malli täydentyy tutkimuksen edetessä, jolloin laajennetun todellisuuden vaikutukset tulevat selkeämmin esiin.

Lopullinen malli pyrkii edellä mainittujen tarjoumien ja niiden tasojen kautta huomioimaan valmistajan, teknisen ohjeen laatijan sekä sen käyttäjän näkemykset. Tällöin se voi toimia tutkimuksellisenä työkaluna sekä tarjota hyötyä laajennetun todellisuuden käyttöönnoton suunnitteluun yrityksissä, teknisten ohjeiden laatimistyöhön

sekä erilaisten ohjesovellusten kehittämiseen ja käyttämiseen. Valmiin mallin avulla voidaan arvioida laajennetun todellisuuden vaikutuksia teknisen ohjeen laadintaan ja tarkastella esimerkiksi yksittäistä ohjetta kaikkien näiden tarjoumien sekä niiden tasojen kautta.

Tarjouman käsitteen pohjalta on mahdollista luoda myös muita, hyvinkin erityyppisiä malleja. Uskomme kuitenkin, että juuri tällä tavalla muodostettu mallin runko soveltuu monipuolisesti erityyppisten aineistojen tarkasteluun sekä laajennetun todellisuuden ottamiseen mukaan erityisen tarkastelun kohteeksi. Malli joustaa ja elää sen mukaan, miten käytännöt vähitellen muuttuvat ja muuttavat lakeja ja säädöksiä. Sen avulla on myös mahdollista tarkastella myöhemmin kehitettäviä teknologioita ja tapoja välittää ohjeita. Se voi myös ohjata ohjeiden laadintaa auttaen keskittymään olennaiseen kaikista tarpeenmukaisista näkökannoista.

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Data Handling Process in Extended Reality (XR) When Delivering Technical Instructions

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By Satu Rantakokko

ABSTRACT

Purpose: Extended reality (XR) is a promising new medium that creates environments combining real and virtual elements or offers a completely virtual environment for people to experience. In the field of technical communication, XR offers a plethora of possibilities, such as augmenting critical instructions in a work environment.

On the downside, XR brings about challenges. For example, issues of privacy and security require more attention due to the risks involved with XR devices continuously collecting data from the users and their surroundings. More knowledge concerning the use of XR as a medium to deliver technical instructions is required. In this article, I address this need by explaining how XR handles data.

Methods: To find out how XR handles data, I used relevant previous research (33 papers and four books) as data for thematic analysis. I coded data systematically according to how XR has been used before and the phases that can be seen in the process of data handling in XR when it is used as a medium for technical instructions.

Results: The data handled in XR can be divided into instructional data, such as assembly instructions, and collected data that XR equipment collects while someone is using it. Data handling in XR can be seen as a process. Based on the thematic analysis, I found six different phases of data handling: collection, processing, storage, transfer, combining, and presentation.

Conclusion: The phases of data handling in XR illustrate in general what happens to the data in XR and what kind of data the equipment collects. My findings add to our understanding of XR as a medium to deliver technical instructions. They also offer a usable framework for mapping the differences between XR and other media as a way to deliver technical instructions.

KEYWORDS: technical instructions, extended reality, mixed reality, virtual reality, augmented reality, augmented virtuality

Practitioner's Takeaway:

- New technologies, such as extended reality (XR), are changing the field of designing technical instructions, and more information is needed.
- XR offers new possibilities for designing technical instructions, but it also poses new challenges.
- An in-depth review of the phases of data handling in XR will help us better understand how data, such as technical instructions and data collected by XR equipment, are handled in XR technology.
- This understanding helps to prevent mistakes, such as leakage of sensitive data, by increasing understanding of how XR works as a medium for delivering technical instructions.

Data Handling Process in Extended Reality (XR)

INTRODUCTION

During the past few years, there has been a rising interest in environments with virtual elements in the field of technical communication. Types of *extended reality (XR)*, such as *augmented reality (AR)* and *virtual reality (VR)*, have been used more and more in delivering technical instructions. Extended reality is becoming a significant part of the work and skillset of many professionals who design technical instructions. To begin using XR as a medium, a technical communicator must understand the types of additional requirements XR applications need for handling data.

Extended reality is an umbrella term that includes both completely artificial virtual reality and *mixed reality (MR)* that combines real and virtual elements. As Fast-Berglund, Gong, & Li (2018, p. 32) defined it, the term “extended reality” refers to “all real-and-virtual combined environments and human-machine interactions generated by computer technology and wearables.” In the use of technical communication, XR offers numerous possibilities. For example, in Figure 1, there is a screenshot from a Youtube video of augmented reality for aircraft maintenance, remote support, and training. This video illustrates how augmented elements can show where and how to use tools needed to complete the task.



Figure 1. Maintenance Instructions (<https://www.youtube.com/watch?v=07dXn9u2WEc>)

Milgram and Kishino's (1994, p. 1321) virtuality continuum, as shown in Figure 2, illustrated the relations between different types of XR. The continuum organized the types of XR by increasing degrees of virtualization. Augmented reality (AR) means layering virtual objects on top of a real environment, while *augmented virtuality (AV)* adds real objects on top of a virtual environment. I will introduce the central terms and types of XR in more detail in the literature review section of the article.

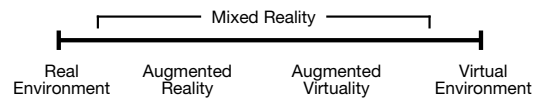


Figure 2. Milgram and Kishino's Virtuality Continuum

According to Azuma's (1997) definition, AR combines virtual and real elements in real time, interactively and three-dimensionally. AR is the best-known type of mixed reality. Azuma's definition is valid for the whole of XR (both MR and VR), except that VR is completely virtual and aims to exclude real elements. Papagiannis (2017) highlighted the importance of imagination and creativity for the uses of XR. It does not only have to mimic reality. Instead, it is possible, for example, to see the invisible or hidden. It is possible to fly and break the laws of gravity. However, there are also potential downsides. XR continuously collects data about the users and their surroundings. That data is needed, for example, to be able to situate the virtual elements in the right places, at the right time.

This collected data can include very sensitive information and is potentially vulnerable to attacks. The importance of privacy and security issues in the design of technical instructions has, therefore, rapidly increased. However, as Ahn, Gorlatova, Naghizadeh, Chiang and Mittal et al. (2018, p. 2) stated, “the field of AR security and privacy is still in its infancy,” even though AR is the most researched field of XR.

In order to address changes occurring within the field, there is a need to study XR as a whole, since different types of XR are increasingly being developed and used in conjunction with each other. During the past couple of years, a few studies have been published to meet this need. As Burova et al. (2020, p. 1) mentioned, “So far, these concepts have been studied separately despite the potential of uniting AR and VR under one comprehensive platform, including cost

savings due to shorter development time, increased efficiency in training, and the possibility to integrate safety related aspects deeper into an organization's culture and processes.”

However, it seems that most research papers on the topic focus only on a certain type of XR, on a certain task (see, for example, Albert et al., 2014). This focus gives a lot of detailed information, but a more comprehensive vision is needed. As Tham et al. (2018) pointed out, professionals working to communicate complex information have recognized the need for more knowledge about emerging technologies, including XR. We can address this need by taking a holistic approach to XR—by examining and taking an overview of how XR handles data. Because there are currently no theoretical perspectives related to XR data handling, I use the grounded theory approach to explore how XR handles data and propose a theoretical framework for future studies in this area. According to Glaser and Strauss (1968, p. 40), “as categories and properties emerge, develop in abstraction, and become related, their accumulating interrelations form an integrated central theoretical framework—the core of the emerging theory. The core becomes a theoretical guide to the further collection and analysis of data.”

The term *data* has a dual meaning in this article. First, it covers the instructions to be delivered by using XR, for clarity here referred to as *instructional data*. Second, it covers the data collected by the XR equipment, here referred to as *collected data*. The purpose of this research is to help professionals who design technical instructions increase their understanding of how XR works as a medium for delivering instructions.

I use the term *data handling* to describe what happens with the data when using XR equipment. For

example, the data is stored, transferred, and presented to the user. I discuss the data handling process in XR from a wide perspective, focusing on the common features of different types of XR. To this end, I conducted a thematic analysis of previous research. As a result, I found six phases of data handling in XR: collection, processing, storage, transfer, combining, and presentation. I introduce these phases in detail in the Results section.

In this article, I focus especially on privacy and security issues because they represent an additional concern brought about by this technology, as traditional modes of technical instructions did not record data about the user, bystanders, and the environment. This focus, however, does not imply that privacy and security issues are more important than other aspects of using a new medium.

LITERATURE REVIEW

In this section, I introduce some of the most recent research concerning extended reality, mixed reality, virtual reality, augmented reality, and augmented virtuality, used in relevant ways for delivering technical instructions.

Extended Reality (XR)

Extended reality is an umbrella term for environments with virtual elements. In Figure 3, I added extended reality in the continuum based on Milgram and Kishino's (1994) virtuality continuum. Combining different types of XR into one project instead of focusing on just one type at a time is a relatively new phenomenon, and there are not many applications like this so far.

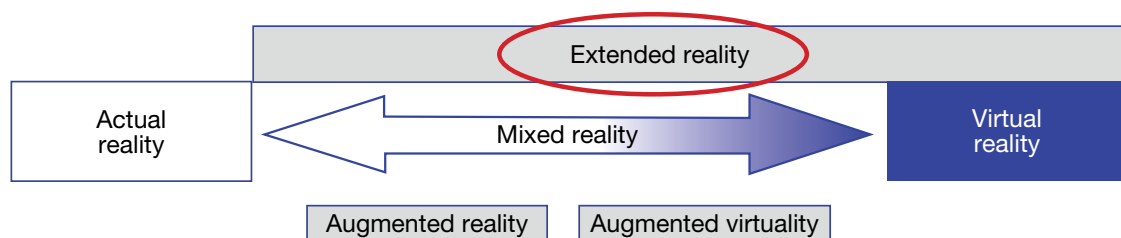


Figure 3. Extended Reality in the Reality-Virtuality Continuum

Data Handling Process in Extended Reality (XR)

Burova et al. (2020) focused on industrial maintenance by developing and evaluating AR content in virtual reality with an xR Safety Kit framework, “a multipurpose VR platform with AR simulation and gaze tracking to support AR prototyping and training” (p. 2). They justified combining VR with AR by pointing out that, in this way, benefits of these different types of XR can be used while minimizing the downsides of both. According to Burova et al. (2020), VR is a viable environment for learning and training thanks to the flexibility and realism of experience, while AR-guidance in-field can improve speed, quality, and safety of work, resulting in decreased physical and mental workload. On the downside, there are challenges in AR development in authoring, context awareness, and interaction analysis.

In their research, Burova et al. (2020) focused on evaluating in-field guidance and safety warnings; their results “show the potential of utilizing VR coupled with gaze tracking for efficient industrial AR development” (p. 2). Their xR Safety Kit framework aimed to approach the challenges in interaction analysis by prototyping AR solutions within VR. Benefits of this kind of a solution include flexibility, reducing development time and costs, and having a safe and controlled way to test techniques. Burova et al.’s (2020) research is a good example of why there is a need for a wider perspective: there are benefits in using more than just one type of XR at a time.

Virtual Reality (VR)

Virtual reality is the other end of the continuum, as illustrated in Figure 4. While actual reality, at the left of the continuum, has no virtual elements, VR consists only of virtual elements. VR has been used in many cases in training for new tasks. It is useful especially when training sessions would be expensive, difficult, or dangerous to conduct in a real environment.

In their research, Porter et al. (2020) focused on the effectiveness of using VR in learning electrostatics. Porter et al. (2020) also studied the relationship between preliminary VR training, earlier gaming experience, and the effectiveness of the learning process in circumstances when the training was not related to the topic to be learned. In general, pretraining improved gains and gaming experience with pretraining even more so. However, gamers who did not receive preliminary training performed worse than other groups, with negative gains. In comparison, untrained non-gamers had small positive gains. In general, some statistical improvement on student performance was witnessed as well as “evidence that VR training is beneficial for student acclimation to VR-based instruction” (p. 8). Porter et al. (2020) concluded that VR-based instructions have no effect on student understanding, meaning that VR-based instructions are not more effective compared to other media at teaching 3D topics. Porter et al.’s (2020) research brings some interesting considerations for designing technical instructions.

First, while XR-based instructions in studies show significant improvement in many aspects compared to traditional instructions, they do not always guarantee improvement in results. Therefore, it is important to consider which medium for instructions is most useful for the purpose at hand.

Second, there is a need to know the target user group. The target user group’s experience matters, even in non-related skills like gaming, and training to use the technology itself may be needed.

Mixed Reality (MR)

Mixed reality exists between actual reality and virtual reality, as seen in Figure 5. When it is stated that a study or application uses MR, it can mean that the

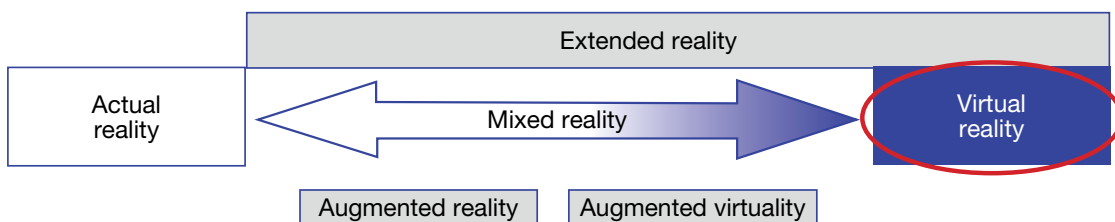


Figure 4. Virtual Reality in the Reality-Virtuality Continuum

application draws from different types of MR or that the application does not fit directly with either of them.

Schoeb et al. (2020) compared MR-based instructions on performing bladder catheter placement to instructions received from an instructor. They used a video-based approach because, as they said, their system did not have the capability to recognize real objects. Therefore, it did not truly “augment” the environment that interacted with real objects, so they categorized it as a mixed reality system. They stated that in practical, medical, and surgical tasks, training often takes place on the patient. This is because other methods, such as simulators, require so many resources that are not widely available. Therefore, cost-effective methods are in high demand. In their results, Schoeb et al. (2020) indicated slightly better learning outcomes with an MR-based solution, with a higher degree of consistency. According to Schoeb et al. (2020) the functionality of this technology is an advantage because it does not require teaching personnel, which makes teaching more flexible and cost efficient. However, they found that it would be difficult to use MR widely in everyday teaching because of shortcomings of the hardware and necessary infrastructure. Schoeb et al. (2020) concluded that MR is an efficient tool for instructing bladder

catheter placement, but more developmental progress is needed to improve the usability of current MR systems.

Schoeb et al.’s (2020) research also mentioned the technological limitations of using MR technology, including the fact that more interaction, which is one of the central features of XR, could have been helpful. This emphasizes the importance of fully using the features of the medium chosen to deliver technical instructions. When considering some type or types of XR, knowledge of their benefits and deficits is needed.

Augmented Reality (AR)

Augmented reality already has a long tradition in delivering technical instructions. In the reality-virtuality continuum, AR is situated closer to actual reality than virtual reality, as shown in Figure 6, because it is based on actual reality augmented with virtual elements.

Chu, Liao, and Lin (2020) studied AR in delivering manual assembly instructions for a complicated task. They focused on Duogong, which is a remarkable architectural design of ancient China, which still plays a vital role in the development of traditional buildings. It is so complex that according to Chu et al. (2020), people tend to have difficulty understanding and learning from 2D drawings and paper documentation.

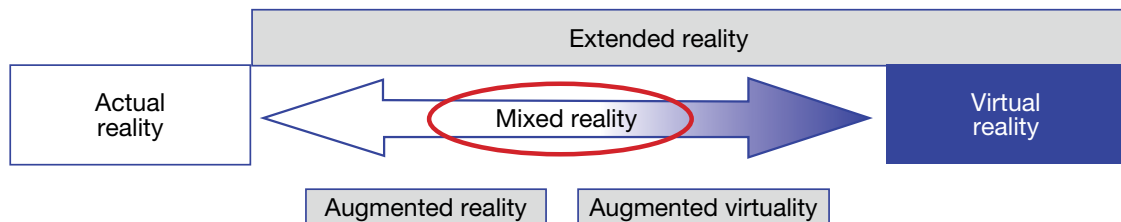


Figure 5. Mixed Reality in the Reality-Virtuality Continuum

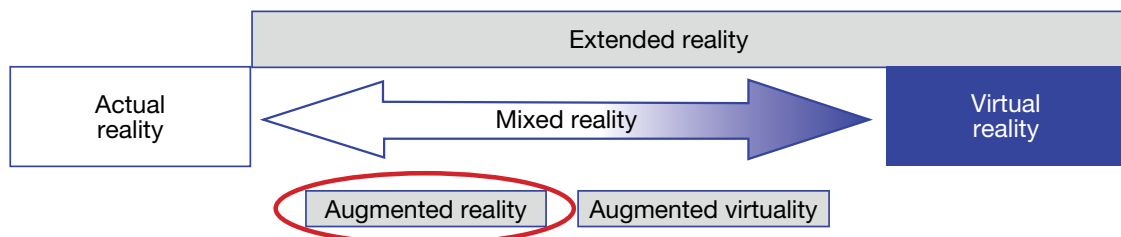


Figure 6. Augmented Reality in the Reality-Virtuality Continuum

Data Handling Process in Extended Reality (XR)

Chu et al. (2020) stated that “assembly instructions, drawings, and operation descriptions are usually presented in a 2D format, or on paper, or both. Such a presentation form fails to precisely demonstrate the spatial relationships among the three-dimensional (3D) components comprising a product, which are critical to its manual assembly” (p. 2). According to Chu et al. (2020), this may increase the assembly time and human errors. Chu et al. (2020) argued that AR applications with their interactive 3D space could solve this problem.

In their study, Chu et al. (2020) proposed two categories of assistive functions: part search and assembly demonstration. Chu et al. (2020) measured assembly time and accuracy, with accuracy as the priority, comparing paper-based instructions, a 3D viewer, and AR-based instructions. After taking a closer look, Chu et al. (2020) discovered that part recognition was slowest with the paper form, and part-fetching took the longest time with the AR system. The AR-based system had the lowest number of assembly errors, but the differences were not statistically significant.

The participants had a relatively lower mental load with paper-based instructions, which, according to Chu et al. (2020), may indicate that people are still accustomed to the paper presentation. Most of the participants considered the part confirmation and assembly demonstration of AR-based instructions highly useful and helpful, but some of them expressed physical fatigue due to placing the parts and assemblies under the camera. According to Chu et al. (2020), participants felt physically and mentally tired by repetitively holding parts under the camera for confirmation purposes.

In this system, the recognition speed was slow, which the participants found frustrating and resulted in longer total assembly time. Chu et al. (2020) concluded

that the system design of AR-based instructions needs to be improved to reduce the computational time required by object recognition.

Since multiple studies show improvements in assembly instructions using AR, Chu et al.’s (2020) study indicates the importance of having good instructional design and having fluently functioning applications. It also signals that at least in the beginning of using new types of instructions, traditions matter. When people are accustomed to reading certain types of instructions, adopting new kinds of instructions and technology may take time.

Augmented Virtuality (AV)

Augmented virtuality is a relatively little used and known type of XR. While augmented reality augments actual reality with virtual elements, augmented virtuality augments virtual reality with real elements. Therefore, in the reality-virtuality continuum, it is situated closer to virtual reality than actual reality, as seen in Figure 7.

Gralak (2020) focused on finding a solution to the greater number of ship collisions caused by increased vessel traffic. According to Gralak (2020), ships are equipped with decision support systems to enhance navigational safety, but these systems “do not provide the navigator with sufficient data for reliable and complete assessment of the ship’s spatial position relative to nearby objects” (Gralak, 2020, p. 2). There is a need for visual observation data, but it may not be feasible, for example, in poor visibility. Therefore, Gralak (2020) aimed to develop an AV-based spatial decision support system to be used in the navigator’s decision-making process.

Gralak (2020) found AV to be more expanded than AR, with more capabilities for this purpose. The main reason for using AV instead of AR was that navigators

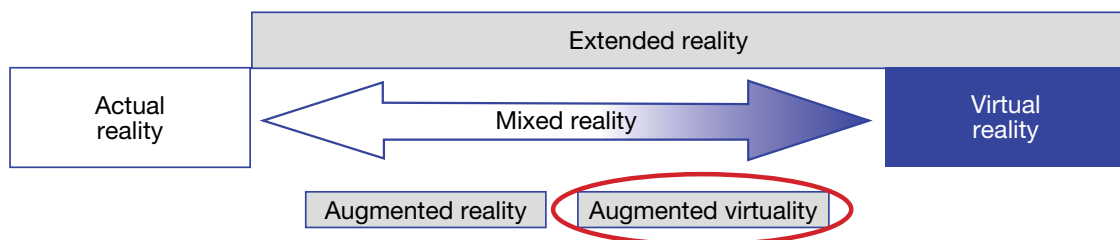


Figure 7. Augmented Virtuality in the Reality-Virtuality Continuum

use visual observation during the decision-making process and, therefore, their view cannot be blocked with virtual elements. Instead, in AV, the “technology provides the observer with a display and interaction in a predominantly or fully virtual world, correlated with reality, which can be enriched with elements of the real environment, presented in a predefined form” (Gralak, 2020, p. 4). The results of this study (Gralak, 2020, p. 15) indicated statistically significant improvement on the safety of navigation; it also indicated that choosing the right type of XR is important because different tasks and goals have different needs.

These examples of recent research illustrate that XR and its different types are used in many ways in delivering instructions. The studies also highlight that it is crucial to understand the features of the technology chosen for the medium to deliver technical instructions and to fully use its benefits for the task at hand. When the features are not fully understood, the potential benefits can be lost. For these considerations, knowledge of how data is handled in XR is needed.

METHODOLOGY

To identify how XR handles instructional data and collected data, I applied thematic analysis (see, for example, Nowell et al., 2017). I focused on how this subject is discussed in earlier relevant research. According to Nowell et al. (2017), thematic analysis is a relevant qualitative research method that can be used when analyzing large qualitative data sets. Nowell et al. (2017) introduced a pragmatic process for conducting a trustworthy, step-by-step approach to thematic analysis, which I have applied in this research. Based on an extensive literature search, I selected relevant sources for literature-based thematic modeling. I explain the methodological process, conducted in six phases, in detail in the next subsection.

Analysis of Literature

The phases of thematic analysis, according to Nowell et al. (2017), are listed in Figure 8. In this section, I provide details about how I applied these phases of thematic analysis in this study.

Phase 1: Familiarization with data

I became familiar with the data by studying earlier research of XR to gain a comprehensive overview. I searched the literature using Google Scholar and the information-seeking portal Finna (<https://finna.fi/Content/about?lng=en-gb>), which covers millions of items from hundreds of organizations, such as archives, libraries, and museums.

In this way, I was able to access a wide range of both open access and limited access research. My search words included the types of XR separately (extended reality, mixed reality, virtual reality, augmented reality, and augmented virtuality) and combined with terms such as technical instructions, instructions, technical communication, and maintenance. In addition, I applied a type of snowball sampling by exploring the research found in the references of previous papers.

I selected 20 papers and four books for closer analysis. The criterion of selection was to enable a broad view of the subject, mostly focusing on, but not limited to, the aspect of XR in mediating technical instructions. However, the focus was not only on earlier and current uses but also on possibilities and challenges that could be relevant to this field.

Thus, I included other kinds of sources as well, including sources concerning technology, future possibilities, and collaboration via XR. I excluded, for example, sources that focused strictly on technology at a very deep level and sources covering specific fields such as architecture or entertainment. My rationale for applying these criteria was to map common features of a wide range of XR from different points of view. The sources selected are introduced briefly in Appendix A.

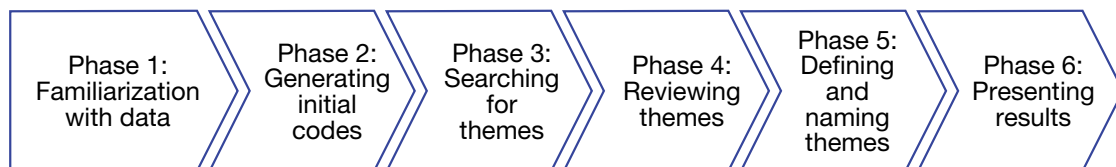


Figure 8. Phases of Thematic Analysis

Data Handling Process in Extended Reality (XR)

Phase 2: Generating initial codes

In phase 2 of the analysis, I generated initial codes by excerpting large, relevant sections discussing the features, effects, and results of the studies, and placed them in a mind map. Next, I divided these sections into subcategories and organized same or similar features under the same nodes in a mind map. This is not a typical method for coding, but it let me systematically go through different sources and find the features they repeatedly discussed, possibly with different terms, as is typical in the field of XR. For example, the basic terms, such as mixed reality and augmented reality, are often confused.

Therefore, I needed to focus on greater overarching codes and what they entail, instead of repeated expressions. Moreover, I needed to keep the purpose of the research in mind. For example, there were several codes to be found that focused deeply on technological processes and equipment in detail, such as different types of technological solutions of screens on an XR headset. That kind of aspect, however, leads to a focus on differences instead of common features. Initial codes that I found were, for example, “what kind of data is available” and “how is data expressed.”

Phase 3: Searching for themes

In searching for themes from the initial codes, it became evident that the approach to data should be process-based. This is because the data is handled in phases that follow each other. Based on the coding of the data, I found six different phases of data handling in XR: collection, processing, transfer, storage, combining, and presentation of data. I elaborate these phases in detail in the Results section.

Phase 4: Reviewing themes

After the phases of data handling in XR were found, they needed to be considered in order to find out if they appear to form a coherent pattern. In this case, I needed to make sure that the aspect of a process can be used in seeing how the data is handled in XR and that all potentially relevant phases of XR data handling were found. Therefore, I decided to test the results with other kinds of sources. Since the risks of privacy and security were a repeated aspect rising during the analysis, I chose the research concerning these issues as the test data. For this purpose, I selected 13 papers concerning security and privacy issues generated by XR use and reviewed them to see if the issues arising from them could be fitted into the phases of data handling in XR. These papers are introduced in Appendix B. In this review phase of the validity of the identified categories, I was able to conclude that the named categories reliably represent the data and are, therefore, useful for this study.

Phase 5: Defining and naming themes and Phase 6: Presenting results

In these phases of the analysis, themes are usually defined, named, and reported. In this research, they were already named in the third phase. I define and report the results in the next section of this paper.

RESULTS

The purpose of this research is to explore and identify the ways in which data is handled when using XR to deliver technical instructions. In particular, it is important to consider the additional requirements in terms of data handling for designers of technical instructions. The analysis of previous research indicates that there are six distinct phases: collection, processing,

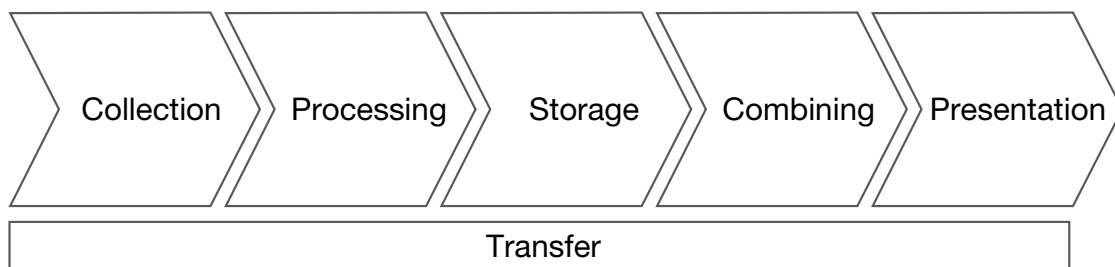


Figure 9. Phases of Data Handling in XR

transfer, storage, combining and presentation of data, illustrated in Figure 9.

The phases of XR data handling are sequential. The phase of data transfer may be conducted on several occasions, for example in order to process or store the data. I discuss each of these phases below in relation to security and privacy issues.

The Collection Phase of XR Data Handling

The first phase of XR data handling is data collection. The data handled in XR includes the instructional data and the collected data. Data collected may be about the user, the surroundings, or bystanders. Figure 10 shows the central aspects of the data collection.

Constant data collection about the users is crucial for XR environments. As Aukstakalnis (2017, p. 196) explained, sensors are a vital enabling technology in XR systems. Their purpose is to track, for example, the user's location, position, orientation, head and hand movements, gestures, eye-movements, actions, and full body dynamics. Without this kind of tracking, XR would not be able to create a real-like, immersive, and interactive experience where all the virtual objects are in the right place at the right time (see, for example, Piumsomboon et al., 2017, p. 36; Reilly et al., 2014, p. 275; De Guzman, Thilakarathna, & Seneviratne, 2019, pp. 8, 13). The instructional application can, for example, collect data from critical situations in a work environment, such as an increased amount of radiation and rising heat.

However, data collection also opens doors to recording sensitive information, for example, from the

user's home and workplace. Everything the user sees and hears can be captured, recorded, and potentially attacked. De Guzman et al. (2019, p. 6) mentioned emails and chat logs as examples of this kind of sensitive data. As another example, the VR-integrated wearable technology company CleverPoint (<https://cleverpoint.pro/>) advertises on its website that its technology is designed to "collect and analyze (the) user's response to VR content," including a neurofeedback function and biometric sensors. It can register, for example, the anger or anxiety of the user.

De Guzman et al. (2019, pp. 10, 14) stated that the main threats in data collection, mostly caused by the constant scanning, are security threats such as tampering, denial of service, and unauthorized access. Other threats besides the security threats are breaches in confidentiality, linkability, detectability, identifiability, and user content unawareness. Bystanders are a part of the surroundings from the XR equipment's perspective, and, therefore, they have to be observed as any other object. This means that bystanders' sensitive data can also be collected, without them possibly even realizing it.

Although there are risks, these risks may be at least partly prevented. There are several ways to protect the data collected. De Guzman et al. (2019, p. 11) suggested, for example, input sanitization techniques, such as "information reduction or partial sanitization, facial information to facial outline only, complete sanitization or blocking, or skeletal information instead of raw hand video capture."

Data collection is the starting point of XR data handling. At the same time, it is the fundamental

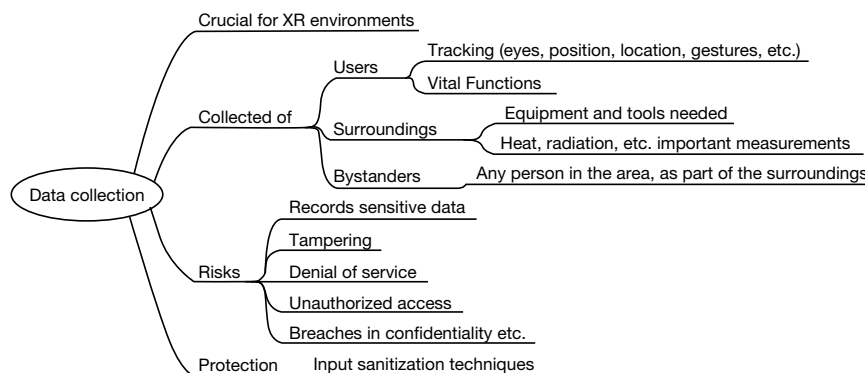


Figure 10. Data Collection Phase of XR Data Handling

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enabler of all the possibilities of XR and also the basic reason for the privacy and security issues of XR-based technical instructions. The data that must be collected because of the nature of XR is a potential risk for privacy and security, therefore, it needs to be protected.

The Processing Phase of XR Data Handling

After the data has been collected, it is then processed. As De Guzman et al. (2019, p. 15) explained, to operate and deliver outputs accurately in real-time, XR equipment also must process the data it keeps collecting. Processing the data is needed to make the data understandable for the XR equipment to create an immersive, real-like, interactive experience. The main points of this data handling phase are seen in Figure 11.

As McPherson, Jana, and Shmatikov (2015, p. 749) stated, processing enables anchoring virtual elements in the right places, which makes it easier to find the right information when it is needed. For example, not only could necessary tools and parts be named, but also pointed out with, for example, an arrow or another symbol. Speed in processing reduces the delay, so that virtual elements appear in the right places, at the right time, when presented to the user.

De Guzman et al. (2019, p. 15) suggested that the same privacy threats of information disclosure, linkability, detectability, and identifiability still hold in the data processing phase as in the data collection phase. According to De Guzman et al. (2019), during the processing, third-party applications or services have direct access to even the most sensitive user data, if no relevant protection is implemented.

Moreover, the data is not always processed on the device. Instead, it can be transmitted to servers for processing. Reasons to outsource the data processing can be, for example, business-related. McPherson et al. (2015, pp. 749–750) mentioned a few examples:

interpolating advertisements, charging content providers, and keeping usage statistics.

Designers of technical instructions can try to protect the data during the phase of data processing by using, for example, encryption-based techniques, secret sharing, or virtual reconstructions, as Adams, Bah, & Barwulor (2018) suggested.

One example of encryption-based techniques is homomorphic encryption, where the data is encrypted upon collection, and a third-party service does not need to decrypt it to carry out computations. This is useful for remote data processing, if the data processors are not reliable (Adams et al., 2018, pp. 15–16). With secret sharing, the data is split between two or more sources, so that the complete data does not have to exist in either source. This technique can be used to secure multi-party computation (Adams et al., 2018, p. 16). In the technique of virtual reconstructions, the real capture of an object is replaced with an artificial one, keeping possibly sensitive objects hidden (Adams et al., 2018, p. 17).

The phase of data processing creates the basis for multiple possibilities in the data presentation phase. Data processing is essential in XR, but it also includes many privacy and security risks.

The Storage Phase of XR Data Handling

The collected and processed data may need to be stored. The phase of data storage allows for continuity. The instructions and other relevant data are preserved and do not need to be collected and processed repeatedly.

Data storage keeps the data accessible at all times. This enables useful features, such as the ability to continue teaching a new task from where it was last left off. A fluent instruction process can make the XR-based instructions feel more reliable.

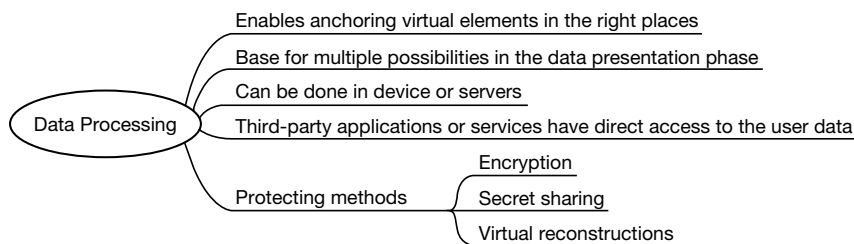


Figure 11. Data Processing Phase of XR Data Handling

According to Adams et al., the data is often stored by the applications in separate databases (2018, p. 17). In those cases, the user has minimal or no control over this stored data. The data storage raises privacy concerns about how the data is used and who has access to it. Attackers may obtain access to the stored data, or the users may be tricked into disclosing information to unauthorized parties. De Guzman et al. (2019, p. 17) listed tampering, unauthorized access, and spoofing as examples of security threats related to data storage.

However, there are data storage solutions to help protect the stored data when trustworthiness is not ensured, such as personal data stores. These give the user control over their own data and allow them to decide which applications have access to it (Adams et al., 2018, p. 17).

Planning data storage is an important part of designing XR data handling. Designers of technical instructions can choose to store only relevant data about the users and their surroundings. The designers of technical instructions and the users both can also take measures to protect the data and prevent access from unauthorized parties.

The Transfer Phase of XR Data Handling

Data may or may not be transferred for different purposes, such as for processing, storage, and presentation. The central points of the data transfer phase are illustrated in Figure 13. Collaboration in XR can be seen as transferring data, such as technical instructions, from user to user. This provides an opportunity for personal counseling in complicated tasks.

As Reilly et al. (2014, p. 275) pointed out, MR is a form of shared space: it combines real and digital elements both local and remote. By merging real and virtual worlds, it creates an interactive and real-time environment. In a similar vein, VR may be used for collaborative purposes as well. Papagiannis (2017, pp. 84–85) emphasized that shared visual spaces allow participants to show data instead of just telling others about the data.

Data transfer to the users is important to give them access to the instructions realistically. If the users work in remote locations, it is important to make sure that at least the most vital instructions can be accessed offline. This way instructions are not useless if the web connection fails. Keeping vital data available offline and minimizing the negative effects of possible interruptions

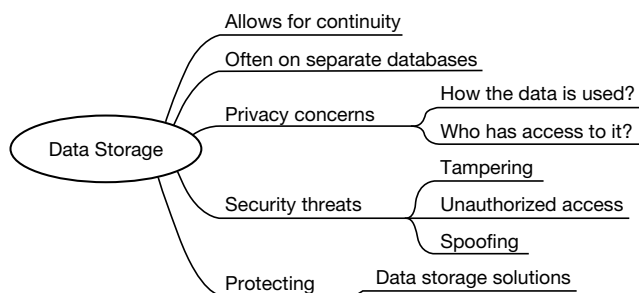


Figure 12. Data Storage Phase of XR Data Handling

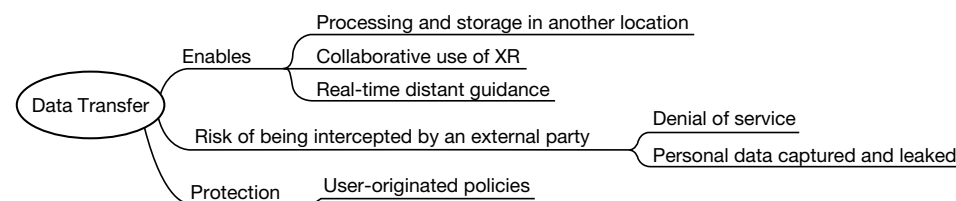


Figure 13. Data Transfer Phase of XR Data Handling

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in data transfer increases trustworthiness of XR-based technical instructions.

Data transfer works in two directions: for the user and from the user. Securing data transfer is important because there is always the possibility that data transfer will be intercepted by an external party. Disruption of data transmission can, at worst, be fatal, if it happens during a dangerous work situation. Even minor deficiencies can lead to personal or business-related data falling into the wrong hands or to a third party adding inappropriate content to the instructions.

For example, in shared spaces an adversarial user could “tamper, spoof, or repudiate malicious actions,” causing legitimate users denial of service or having their personal data captured and leaked (Adams et al., 2018, p. 21). McPherson et al. (2015, p. 750) stated that the users usually have no way to find out which data is sent to servers. This could reduce users’ reliance on XR as a mediator of technical instructions. Keeping users informed of what data is transferred and to whom could improve users’ trust and reliance on applications.

One important set of tools for data transfer protection is user-originated policies, such as Emmi (Environmental Management for Multi-user Information environments), which allow users to hide specific virtual objects in a collaborative environment, or Kinected Conference, which enables gesture-based requests for temporary private sessions during collaborative actions. Another example is feed-through signaling, such as SecSpace, which allows “a more natural approach to user management of privacy in a collaborative MR environment” (De Guzman et al., 2019, p. 21).

Data transfer enables the processing and storage of the data in another location. It also offers a chance for collaborative use of XR, and it is vital for real-time distant guidance in work situations. Real-time transfer in both directions makes it more difficult to protect sensitive data, since the other users see, may capture, and perhaps even save everything. The data is vulnerable to being captured by a third party during the transfer.

The Combining Phase of XR Data Handling

By combining data from the user’s environment, location, and movements, instructions can assist in a real-time and interactive manner. Roesner, Kohnno, and Molnar (2014, pp. 95–96) stated that by combining several input and sensory devices, future systems could, for example, detect privacy or security conditions that the user should be warned about, such as camera lenses or a laser microphone pointed at them or physical deception attempts like card-skimming devices in the ATM. This phase is introduced in Figure 14.

Combining data from technical instructions with a work environmental view enables access to interactive instructions. This is useful especially in complicated tasks when the users need the instructions shown instead of spoken or written to increase the possibility of understanding. With XR, the users can also be informed of security, privacy, and safety risks in the environment, and be guided to solve these situations. These benefits can add to user safety and evoke a more positive attitude toward XR-based instructions.

Combining data from different sources can lead to leakage of private and sensitive data (see, for example, Acquisti, Gross, & Stutzman, 2014, pp. 13–14). All the previously mentioned solutions and suggestions for privacy and security challenges may have a positive effect on the data-combining challenge. For example, denying unauthorized access to collected and stored data protects it from being captured and combined with data from other sources.

Data combining enables and supports some of the most significant possibilities that XR can offer, yet at the same time, risks are posed by its ability to combine sensitive data to achieve more knowledge about the user, an organization, or a bystander. Protection methods in the previous XR data handling phases decrease risks of data-combining by hostile parties.

The Presentation Phase of XR Data Handling

Finally, the data is presented to the user. The data can include sensory information, such as visual, audio, tactile, and olfactory (Happa, Glencross, & Steed,

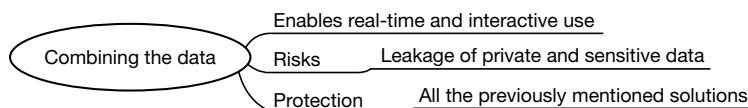


Figure 14. Data Combining Phase of XR Data Handling

2019, p. 11). In this phase, the multiple possibilities enabled by data collection, processing, and combining become visible to the user. Features of XR can, in many cases, increase user safety remarkably. Albert et al. (2014, p. 9) highlighted that workers are often unable to recognize hazards, and hence are exposed to safety risks. They studied enhancing construction hazard recognition with high-fidelity augmented virtuality and found that “the intervention significantly improved hazard recognition and communication” (Albert et al., 2014, p. 9). The data presentation phase is introduced in Figure 15.

Presentation of the data makes accessing it easier, for example, by showing vital instruction data directly to the users when the situation requires that data, allowing user to have easy access to situation-related alarms and warnings. Well-presented data is easy to find and notice in the situations the users operate in.

Aukstakalnis (2017, p. 332) stated that 80%–85% of human perception, learning, cognition, and activities are mediated through vision. Using unambiguous symbols, focusing on visual elements that are, if needed, supported with auditory and tactile elements, can also increase the probability of understanding the instructions. In reliable instructions, the presentation is at all times, or at least almost all times, functional and uninterrupted.

Badly designed, malicious, or bug-ridden applications can compromise user security. For example, the application can require too much of the user’s attention, causing distractions, or it can block crucial objects of the environment, such as road-signs, from being noticed (Ahn et al., 2018, pp. 1–2). Lebeck, Ruth, Kohno, and Roesner (2017, p. 322) mentioned, as an example, that the AR game Pokémon Go captured the attention of its users to the extent

that the game posed recurring safety risks in traffic, and even physiological damage can be caused to the user by “sensory overload, caused by flashing visuals, shrill audio, or intense haptic feedback signals.” De Guzman et al. (2019, p. 18) stated that user safety can be compromised by tampering or spoofing outputs because of the loose output access control of current ‘reality’ systems. Compromised reliability can result in threats, for example, denial of service, and policy and consent non-compliance. If an untrusted or malicious application obtains access to other outputs, it can potentially modify those outputs, making them unreliable, or overlay content (De Guzman et al., 2019, p. 7; McPherson et al., 2015, p. 750). A well-functioning presentation can make the instructions seem even more trustworthy while tampered output can reduce the probability of relying on the data.

There are several ways to protect the data in the data presentation phase, such as encrypting the content so that it can only be decrypted by the XR systems of the intended recipients. Extended reality also offers some improvements in privacy compared to other forms of instruction. For example, shoulder surfers and rubber-neckers are blocked from seeing the password, since, as Roesner et al. (2014, pp. 95–96) noted, applications are visible to the users’ eyes only.

Data presentation is the visible part of technical instructions to the user. Well-functioning instructions give the needed data at the right time but do not flood the user with unimportant data, blocking their view or demanding attention.

CONCLUSION

In this article, I have explained how extended reality handles instructional data and collected data to increase

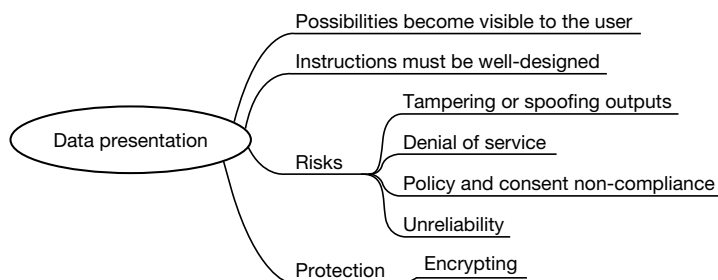


Figure 15. Data Presentation Phase of XR Data Handling

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knowledge needed for designing XR-based technical instructions. I also identified the phases in which the data is handled. These phases are collection, processing, storage, transfer, combining, and presentation.

The purpose of identifying these phases of data handling in XR is to help technical communicators understand what happens to the data with the XR technology and how it is different from other media for delivering instructions. The issues of safety and privacy were discussed in detail because they are a new challenge in XR-based technical instructions, compared to other formats.

This study has some limitations. First, it offers only one way to look at XR as a medium to deliver technical instructions. There are other possible aspects as well, such as comparing technological benefits and requirements of different types of XR. Second, since the focus in this study is on general and common features of XR, it excludes focusing on possible differences in the phases of XR data handling of different types of XR.

Many privacy and security risks can be minimized by taking actions in the early stages. There are signs that privacy and security issues will increase in the future when the technology becomes more ubiquitous and widespread, and these issues may be exacerbated with artificial intelligence or data mining. Thus, more research is needed on the issues of privacy and security.

Further research is also needed to take a closer look at how these phases of XR data handling affect designing technical instructions. Furthermore, more research on comparing features of different types of XR is needed to help technical communicators choose the type or types of XR that would best support delivering their specific technical instructions.

Still, seeing data handling as a process enables a detailed review of XR as a medium to deliver technical instructions, which may help with organizing the design process of XR-based technical instructions.

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Data Handling Process in Extended Reality (XR)

APPENDIX A	
Author(s), title, and number of references in Google Scholar	Introduction of the book / paper, the publisher, and its H Index according to Scimago Journal & Country Rank (SJR). H Index quantifies scientific productivity and scientific impact.
Features of XR	
Papagiannis (2017): <i>Augmented human: How technology is shaping the new reality.</i> Number of references: 63.	Focused on the possibilities of AR in her book. Took a look in not only visual AR, but also tactile, audio, and olfactory. Her aspect was "seeing the world anew" with this fascinating technology. Published in <i>O-Reilly Media</i> . Not listed in SJR.
Graig (2013): <i>Understanding augmented reality: Concepts and applications.</i> Number of references: 469.	Focused on hardware and software of AR systems, introducing in detail the major components of both. Also took a look in interaction and applications in AR. Published in <i>Morgan Kaufman</i> . Not listed in SJR.
Aukstakalnis (2017): <i>Practical augmented reality: A guide to the technologies, applications, and human factors for AR and VR.</i> Number of references: 151.	Introduced technologies and applications of both AR and VR from many aspects, such as virtual spaces and human senses. Took a look at the many fields that these technologies are used in, such as education and engineering. Published in <i>Addison-Wesley</i> . Not listed in SJR.
Tham et al. (2018): "Understanding virtual reality: Presence, embodiment, and professional practice." Number of references: 34.	Focused on the functions, features, and uses of Google Cardboard, Google Daydream View, and HTC Vive. Aimed to showcase current or potential deployments with modified heuristics. According to the results, VR immersion can provide students with a deeper understanding of the content to be learnt, and an initial vision of the project and profession. Published in <i>IEEE Transactions on Professional Communication</i> . H Index 42.
Mediating Instructions	
Zauner et al. (2003): "Authoring of a mixed reality assembly instructor for hierarchical structures." Number of references: 183.	Introduced a MR application, Authoring Wizard, for step-by-step assembly of furniture for assembly experts. It allowed users to be authors as well. It was also able to select components and define and store all types of elements. Published in <i>The Second IEEE and ACM International Symposium on Mixed and Augmented Reality, Proceedings</i> . Not listed in SJR.
Doshi et al. (2017): "Use of projector based augmented reality to improve manual spot-welding precision and accuracy for automotive manufacturing." Number of references: 81.	Focused on a projector-based spatial augmented reality (SAR) and its use in manual spot-welding operations. SAR was used to highlight spot-weld locations on vehicle panels. The results indicated better accuracy and increase in precision with AR system than without it. Published in <i>The International Journal of Advanced Manufacturing Technology</i> . H Index 112.
Benbelkacem et al. (2013): "Augmented reality for photovoltaic pumping systems maintenance tasks." Number of references: 42.	Proposed an AR platform with a tracking system for maintenance tasks to stabilize water supply for remote regions and deserts. The results indicate, e.g., flexibility and time saving. Published in <i>Renewable Energy</i> . H Index 174.
De Amicis et al. (2017): "Augmented reality for virtual user manual." Number of references: 25.	Proposed an AR-based method to support the assembly of components, creating a virtual user manual in an AR environment. The manual recognized and identified the components and combined VR procedure with typical AR process in motion tracking. Published in <i>International Journal on Interactive Design and Manufacturing (IJIDeM)</i> . H Index 20.

Author(s), title, and number of references in Google Scholar	Introduction of the book / paper, the publisher, and its H Index according to Scimago Journal & Country Rank (SJR). H Index quantifies scientific productivity and scientific impact.
Tang et al. (2003): "Comparative effectiveness of augmented reality in object assembly." Number of references: 587.	Conducted a study to test the relative effectiveness of AR instructions in an assembly task. The results suggest that AR can improve task performance and relieve mental workload on assembly tasks, being more effective instructional medium. Published in <i>Chi '03 Proceedings of the SIGCHI Conference on Human Factors in Computing Systems</i> . Not listed in SJR.
Tzimas et al. (2019): "Machine tool setup instructions in the smart factory using augmented reality: A system construction perspective." Number of references: 15.	Created an AR demonstrator highlighting the feasibility of low-cost, efficient, and user-friendly AR applications for industrial guidance and training. Focused on technical aspects and developed an application that aimed at "supporting the turning center operator in clamping rotational parts." Published in <i>International Journal on Interactive Design and Manufacturing (IJIDeM)</i> . H Index 20.
Yew et al. (2016): "Towards a griddable distributed manufacturing system with augmented reality interfaces." Number of references: 65.	Described a framework for computer-integrated AR manufacturing system. It aims to improve the information perception of the different types of workers in a manufacturing facility and to make interaction with manufacturing software natural and efficient. Published in <i>Robotics and Computer-Integrated Manufacturing</i> . H Index 84.
Evaluation	
Elia et al. (2016): "Evaluating the application of augmented reality devices in manufacturing from a process point of view: An AHP based model." Number of references: 81.	Developed an AHP model to quantitatively evaluate AR devices in manufacturing. The results suggest that reliability and agility are the most important features to an AR device. These features support information exchange during the maintenance task. Published in <i>Expert Systems with Applications</i> . H Index 184.
Arbeláez-Estrada and Osorio-Gómez (2013): "Augmented reality application for product concepts evaluation." Number of references: 20.	Proposed an AR application for Android mobile devices to help decision-making activities through the design process. The designer is able to get feedback of the user through their own mobile device and context, getting the user's visual experience, thus making evaluation process less subjective. Published in <i>Procedia Computer Science</i> . H Index 59.
Hazard Recognition	
Albert et al. (2014): "Enhancing construction hazard recognition with high-fidelity augmented virtuality." Number of references: 133.	Developed Systems for Augmented Virtuality Environment Safety (SAVES) to help develop workers' hazard recognition skill in dynamic environments. The results indicated significant improvement in hazard recognition and communication, and potential benefits in occupational health and safety training. Published in <i>Journal of Construction Engineering and Management-ASCE</i> . H Index 105.
Usability	
Olsson (2012): "User expectations and experiences of mobile augmented reality services." Number of references: 34.	Aimed to understand both user expectations and the actual UX of the first-generation mobile augmented reality applications. Studied expected experiences, and both satisfying and unsatisfying actual experiences. Published in <i>Tampere University of Technology</i> . Not listed in SJR.
Dey et al. (2018): "A systematic review of 10 years of augmented reality usability studies: 2005 to 2014." Number of references: 140.	Reviewed and classified, based on their application areas, 291 papers with 369 individual user studies. Aimed to "present the broad landscape of user-based AR research, and to provide a high-level view of how that landscape has changed." Published in <i>Frontiers in Robotics and AI</i> . H Index 21.

Data Handling Process in Extended Reality (XR)

Author(s), title, and number of references in Google Scholar	Introduction of the book / paper, the publisher, and its H Index according to Scimago Journal & Country Rank (SJR). H Index quantifies scientific productivity and scientific impact.
Training	
Hoedt et al. (2017): "The evaluation of an elementary virtual training system for manual assembly." Number of references: 20.	Studied the effect of an elementary virtual training for manual assembly task. According to the results, the assembly rate in the virtual environment was much faster than in real environment allowing more iterations during the training period, but the real training improved assembly time more than the virtual training. Published in <i>International Journal of Production Research</i> . H Index 125.
Webel et al. (2013): "An augmented reality training platform for assembly and maintenance skills." Number of references: 287.	Developed a novel concept and platform for multimodal AR-based training of maintenance and assembly skills, including sub-skill training and the evaluation of the training system. Noticed that training with an AR-based platform caused less errors and better performance times and faster training. Published in <i>Robotics and Autonomous Systems</i> . H Index 109.
Westerfield et al. (2015): "Intelligent augmented reality training for motherboard assembly." Number of references: 155.	Investigated a combination of AR with Intelligent Tutoring Systems (ITS) to assist with training for manual assembly tasks. Developed a modular software framework for intelligent AR training systems, and a prototype that teaches novice users to assemble a computer motherboard. Published in <i>International Journal of Artificial Intelligence in Education</i> . H Index 45.
Effects	
Miller et al. (2019): "Social interaction in augmented reality." Number of references: 47.	Conducted three studies in order to test the social psychological effects of AR. Noticed that virtual humans in AR can socially influence performance. Interaction between two AR users with one of them occluded by virtual content did not lead to differences, but AR users compared to the users not wearing an AR headset tended to have lower social presence and IOS scores. Published in <i>PLoS ONE</i> . H Index 300.
Design Process	
Bruno and Muzzupappa (2010): "Product interface design: A participatory approach based on virtual reality." Number of references: 122.	Evaluated a participatory design approach where VR was both a tool to evaluate the usability of the virtual product interface, and a communication channel enabling users to directly participate in the design process as co-designers. Published in <i>International Journal of Human Computer Studies</i> . H Index 116.
Nebeling et al. (2018): "ProtoAR: Rapid physical-digital prototyping of mobile augmented reality applications." Number of references: 25.	Introduced an easier and less time-consuming way to create content in AR, ProtoAR. It enables the physical prototyping with paper and Play-Doh, which is then generated into virtual content with ProtoAR tools. Published in <i>CHI '18 Proceedings of the 2018 CHI conference on Human Factors in Computing Systems</i> . Not listed in SJR.
Interaction	
Piumsomboon et al. (2017): "Exploring natural eye-gaze-based interaction for immersive virtual reality." Number of references: 89.	Explored strengths and weaknesses of three eye-gaze based interaction techniques inspired by natural eye movements: Duo-Reticles, Radial Pursuit, and Nod and Roll. Found positive results in, e.g., preference, satisfaction, and fatigue. Published in <i>2017 IEEE Symposium on 3D User Interfaces, (3DUI) 2017-Proceedings</i> . H Index 9.
Symbols	
Scurati et al. (2018): "Converting maintenance actions into standard symbols for augmented reality applications in Industry 4.0." Number of references: 50.	Proposed to create and adopt a vocabulary of graphical 2D symbols to be used in AR to represent maintenance instructions. The results indicate that this approach was simple and lowered mental load of the users, and that 2D symbols have value for the frequent general purpose tasks, while 3D are better for very complex customized operations. Published in <i>Computers in Industry</i> . H Index 93.

APPENDIX B

Author(s), title, and number of references in Google Scholar	Introduction of the book / paper, the publisher, and its H Index according to Scimago Journal & Country Rank (SJR). H Index quantifies scientific productivity and scientific impact.
Risks	
Acquisti et al. (2014): "Face recognition and privacy in the age of augmented reality." Number of references: 81.	Conducted studies to combine online-data with face recognition. Succeeded to identify 10% of a dating site's profiles based on Facebook, and 33% of people walking by the campus based on social network data, cloud computing and a facial photography. Also found a significant amount of online information of the identified persons, such as sexual orientation or Social Security numbers. Published in <i>Journal of Privacy and Confidentiality</i> . Not listed on SJR.
De Guzman et al. (2019): "Security and privacy approaches in mixed reality: A literature survey." Number of references: 31.	Focused on recent research concerning security and privacy risks and protection approaches of MR and VR. Found that only a few (1,42% of 2016) are discussing the impacts, or presenting security and privacy approaches applied to, or using, XR. Published in <i>ACM Computing Surveys</i> . H Index 143.
Happa et al. (2019): "Cyber security threats and challenges in collaborative mixed-reality." Number of references: 8.	Investigated the cyber-security challenges of CMR systems in MR. Focused on network architectures facilitating CMR, its vulnerabilities, and the social, monetary, psychological, and other harms they may result from exploits. Presented an abstraction-based reasoning framework to identify potential attack vectors. Published in <i>Frontiers in ICT</i> . H Index 12.
McPherson et al. (2015): "No escape from reality: Security and privacy of augmented reality browsers." Number of references: 21.	Analyzed the functional requirements of AR browsers and investigated the security architecture of Junaio, Layar, and Wikitude. Identified multiple architectural flaws that caused security and privacy risks. Proposed short-term solution suggestions. Published in <i>WWW 2015—Proceedings of the 24th International Conference on World Wide Web</i> . H Index 29.
Rauschnabel et al. (2018): "Antecedents to the adoption of augmented reality smart glasses: A closer look at privacy risks." Number of references: 94.	Developed a theoretical model to assess AR smart glasses (ARSG). Noticed that utilitarian, hedonic, and symbolic benefits drive consumers' reactions to ARSG, and that ARSG's threat of privacy for bystanders can influence users' decision-making rather than privacy threat of their own. Published in <i>Journal of Business Research</i> . H Index 179.
Solution Suggestions	
Ahn et al. (2018): "Adaptive fog-based output security for augmented reality." Number of references: 18.	Proposed a method for generating adaptive policies to secure visual output in AR systems using deep reinforcement learning. In their approach, a local fog node runs training simulations to learn an appropriate policy for filtering potentially malicious or distracting content of an application. Published in <i>VR/AR Network 2018—Proceedings of the 2018 Morning Workshop on Virtual Reality and Augmented Reality Network, Part of SIGCOMM 2018</i> . Not listed in SJR.
Lebeck et al. (2017): "Securing augmented reality output." Number of references: 40.	Focused on security and privacy issues especially concerning the data presentation phase. Developed Arya, an AR based platform architecture that focuses on output security. Arya succeeded to address many output security issues without making reasonable performance impossible. Published in <i>2017 IEEE Symposium on Security and Privacy</i> . Not listed in SJR.
Ferreira et al. (2007): "Security and privacy in a middleware for large scale mobile and pervasive augmented reality." Number of references: 6.	Proposed, tested, and analysed a security and privacy architecture for a previously proposed middleware architecture for mobile and pervasive large scale AR games. Also described security and privacy issues and the solution suggestions. Published in <i>2007 15th International Conference on Software, Telecommunications and Computer Networks</i> . H Index 6.

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Author(s), title, and number of references in Google Scholar	Introduction of the book / paper, the publisher, and its H Index according to Scimago Journal & Country Rank (SJR). H Index quantifies scientific productivity and scientific impact.
Reilly et al. (2014): "Prototyping usable privacy and security for mixed reality collaborative environments." Number of references: 13.	Presented SecSpace, a software toolkit for usable privacy and security research for MR collaboration. SecSpace "permits privacy-related actions in either physical or virtual space to generate effects simultaneously in both spaces." Published in <i>2007 15th International Conference on Software, Telecommunications and Computer Networks</i> . H Index 6.
Roesner et al. (2014): "Security and privacy for augmented reality systems." Number of references: 156.	Focused on security and privacy challenges with AR technologies especially concerning data collection and data presentation. Suggested solutions for some of these. Published in <i>Communications of the ACM</i> . H Index 203.
Bystanders' Privacy	
Denning et al. (2014): "In situ with bystanders of augmented reality glasses: Perspectives on recording and privacy-mediating technologies." Number of references: 146.	Focused on the bystanders of AR glasses with field studies and interviews. The results suggest that a significant part of the bystanders (11 of 31) do not pay attention that someone nearby is wearing AR glasses. Almost every participant reacted indifferently (16) or negatively (12) to the idea of being recorded by an AR device. Published in <i>CHI'14: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems</i> . Not listed in SJR.
Privacy Policies	
Adams et al. (2018): "Ethics emerging: the story of privacy and security perceptions in virtual reality." Number of references: 16.	Focused on privacy and security perceptions in VR from the aspect of privacy policies and ethics. Noticed that the users and the developers are mainly concerned about risks of well-being, security, and privacy. Also found significant deficiencies in the privacy policies. Published in <i>Proceedings of the Fourteenth Symposium on Usable Privacy and Security</i> . Not listed in SJR.
Increasing Safety	
Lukosch et al. (2015): "Providing information on the spot: Using augmented reality for situational awareness in the security domain." Number of references: 49.	Developed an AR system to support information exchange in the security domain, especially concerning situational awareness within the expert teams that need relevant and up-to-date information for quick decision-making. The results suggest that the AR system was suitable for the tasks, and improved collaboration of the teams. Published in <i>Computer Supported Cooperative Work</i> . H Index 63.

Creating a Model for Developing and Evaluating Technical Instructions that use Extended Reality

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By Satu Rantakokko

ABSTRACT

Purpose: Extended reality (XR) is an umbrella term for the many ways that we can now design 3D, interactive, and real-time environments as in combining virtual and real elements, and experience immersion in a completely virtual reality (VR). The use of XR is increasing in popularity across a range of industries. Although researchers are becoming increasingly interested in the benefits and challenges of using XR to convey technical instructions, more comprehensive research is required. I aim to address this need in the present article by introducing an affordance model of Technical Instructions in Extended Reality, the TIER model.

Two earlier categorizations, the affordances of technical instructions, and the phases of data handling in XR, formed the point of departure for this article. The analysis utilized a four-category model of affordances by Rantakokko and Nuopponen (2019) that comprised: accessing, finding, understanding, and relying on. Data handling in XR drew on a phase-based model by Rantakokko (2022) featuring: collection, processing, storage, transfer, combining, and presentation.

Methods: The two sets of categorizations were combined into a holistic model with an iterative process in order to offer a tool for analyzing and describing the possibilities and challenges that XR brings to designing technical instructions. The iterative process was conducted by adding examples from existing research into matrix tables to understand how the affordances of technical instructions and the phases of data handling in XR are connected.

Results: The TIER model is introduced with examples to illustrate how it can be used to view every phase of XR data handling in terms of the affordances of technical instructions based on the laws, regulations, principles of good guidance, and the design process.

Conclusion: The TIER model can be used as a tool for an organized, step-by-step design process as well as testing XR-based technical instructions to ensure that the features of XR support the intended affordances of technical instructions.

KEYWORDS: technical instructions, affordances, extended reality, mixed reality, virtual reality

**Practitioner's
Takeaway:**

- XR offers new possibilities (i.e., interactive, 3D, and real-time instructions) and challenges (i.e., privacy-related challenges) for designing technical instructions.
- More research is needed to fully benefit from the possibilities of various types of XR and avoid or minimize the new risks.
- The affordance model of Technical Instructions in Extended Reality (TIER) model is a tool for organizing the design process of XR-based technical instructions.
- The TIER model also offers an organized means for testing the XR-designed technical instructions.
- Although the TIER model is mainly focused on the perspective of the designers of technical instructions, it can also be used as a research framework.

INTRODUCTION

For as long as there have been technical devices, there have been instructions on how to use them. These instructions can take many forms, such as face-to-face guidance, paper manuals, online-instructions, videos, audios, pictures, etc., as long as they fulfill their main purpose: to guide users preparing to use or operate a technological product. However, the recurring challenge is how to encourage users to read the instructions they need, especially if they opt to immediately begin to test the technical device. According to Novick and Ward's research (2006), paper manuals were the most rejected form of instructions; it was more common for users to give up on the project rather than use the printed manuals.

Professional communicators have noted this challenge and have searched for novel solutions. One of many such efforts is related to emerging technologies. *Extended reality (XR)* is considered a promising medium for delivering technical instructions and capturing the users' interest. XR is an umbrella term

for all the three-dimensional, interactive, and real-time environments with virtual elements (see, e.g., Fast-Berglund, Gong, & Li, 2018, p. 32). It includes *mixed reality (MR)* and *virtual reality (VR)*. Furthermore, mixed reality includes *augmented reality (AR)* and *augmented virtuality (AV)*. These concepts and their relations are illustrated in a reality-virtuality continuum by Rantakokko (2022, adapted from Milgram & Kishino, 1994, p. 1321) in Figure 1.

Actual reality is the natural environment without virtual elements in it. Instead of diving deep in the ever-lasting philosophical debate about the concept of *real*, I quote the Merriam-Webster online dictionary (2022), which defines *real* among other things as "having objective independent existence"; "not artificial, fraudulent, or illusory"; "occurring or existing in actuality"; and "existing as a physical entity and having properties that deviate from an ideal, law, or standard." With these definitions, from the point of view of this research, actual reality can be defined as "the totality of real things that occur or exist in actuality as physical entities which are not artificial, fraudulent, or illusory,

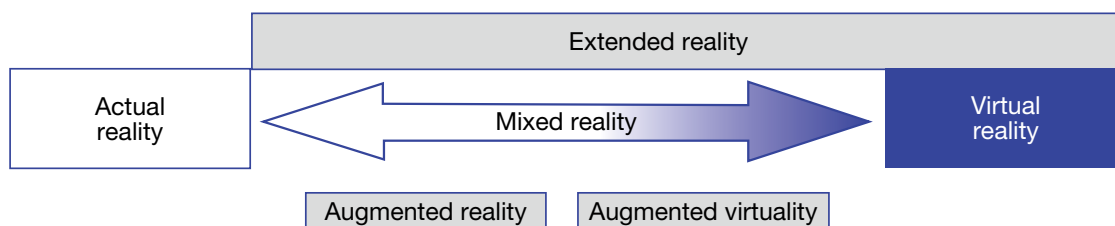


Figure 1. Reality-virtuality continuum (Rantakokko, 2022)

Creating a Model for Developing and Evaluating Technical Instructions

and which have objective independent existence.” XR breaks the boundaries of the perception of reality. At its best, added virtual elements are detected and experienced in a similar way to real elements. Yet, instead of existing in physical reality, they only exist as virtual enhancements.

VR aims to create a completely artificial, virtual experience with no real elements included. It is useful, for example, for virtual training if skills need to be practiced in a safe environment or with less costs (Hoedt et al., 2017). MR includes both real and virtual elements. In mixed reality, two types can be separated: augmented reality (AR) and augmented virtuality (AV). AR is based on actual reality that is enriched with virtual elements, while AV is based on a virtual environment enriched with real elements (see, e.g., Ternier et al., 2012, p. 2146). AR can be used, for example, to offer phase-by-phase manual assembly instructions, pointing out to the user which component to assemble next (de Amicis et al., 2017). AV enables, for example, distance meetings in a virtual, interactive meeting room so that participants can see each other live while interacting with virtual objects in the meeting room (Regenbrecht et al., 2003).

In previous research, the focus has typically been on a certain type of XR, in relation to a specific task (see, e.g., Albert et al., 2014; Zauner et al., 2003; Doshi et al., 2017). However, often, optimal benefits are achieved when combining different types of XR. Furthermore, it is important to consider the common and general features of XR as a whole to gain an understanding of how this technology works and how it can be utilized to support the features of well-functioning technical instructions. Consequently, there is a need for a comprehensive and more in-depth view on the subject.

Using XR to deliver technical instructions requires new approaches. For example, according to Burova et al. (2020, p. 3), “existing, traditional technical documentation content does not work when viewed with AR glasses.” This is due to the fact that there is too much text. This characteristic renders relevant passages difficult to find and understand. Commencing the use of an emerging form of technology as a tool requires careful consideration from the designers of technical instructions to fully utilize its possibilities and to avoid mistakes. More knowledge of the features and nature of XR as a medium are required to understand its

benefits as well as possible hindrances and effects. These needs can be addressed with a theoretical model that serves as a tool for the designers of XR-based technical instructions to analyze both the possibilities and challenges posed by using XR. In this article, I propose such a model to extend the discussion of using XR as a tool to deliver technical instructions.

The model I introduce in this article, for the purpose of analysis, is for professionals of technical communication who are planning to use XR as a medium for delivering technical instructions for a target user group. This model offers a comprehensive view on XR as a tool and an organized way to view the design process of XR-based technical instructions.

In general, using XR as a medium to deliver technical instructions offers multiple novel possibilities. Through using XR, technical instructions can be made interactive, context-related, and three-dimensional, and they can also combine multiple virtual elements, such as text, pictures, and videos related to the real environment (Azuma, 1997). This increases the likelihood that the user receives vital information when required. Furthermore, since the instructions are available during the tasks and without interrupting the task-related actions in order to read them, it is more likely that users will actually use the instructions.

On the downside, XR requires certain equipment to function; currently this typically includes headsets or smartphones and tablets as a bare minimum. Despite technological advances in recent years, this equipment still has problems, such as the cumbersome nature of the devices and delays (see, e.g., Aukstakalnis, 2017). Another challenge is that the nature of XR is to constantly collect the data of users and their environment, thus bringing new kinds of cyber security challenges into the field (see, e.g., Piumsombon et al., 2017, p. 36; Reilly et al., 2014, p. 275; de Guzman, Thilakarathna, & Seneviratne, 2019, pp. 8, 13).

With other media, such as paper manuals, video instructions etc., these challenges have not been significant concerning technical instructions since instructions do not usually include the collection of sensitive and personal data. In the case of XR, the collection of sensitive data is difficult, if not impossible, to avoid, and is thus vulnerable to attack. This risk of attack results from the fact that in order to situate virtual objects in the right place at the right time, XR equipment must track, for example, the user’s location,

orientation, gestures, eye movements, and surroundings. XR equipment includes multiple sensors to fulfill these tracking demands (see, i.e., Aukstakalnis, 2017, pp. 20–21). For instance, as de Guzman, Thilakarathna, and Seneviratne (2020, p. 1) mentioned, the requirement of spatial understanding of the user environment leads to spatial maps, which may contain sensitive information that the user did not intend to expose. This sensitive information can be further utilized for unintended functionalities, such as aggressive localized advertisements or even theft. De Guzman et al. (2020) also stated that there are no mechanisms in existing MR platforms that would ensure user spatial data privacy. What makes this issue even more concerning is that this spatial data is perceptually unknown to the users. Instead, they are “oblivious about the captured spatial mapping, its resolution, and exactness” (de Guzman et al., 2020, pp. 1–2).

The affordance model of Technical Instructions in Extended Reality, the TIER model, includes two main elements: technical instructions and XR as the medium delivering them. I will discuss the possibilities and challenges of XR for delivering technical instructions by taking *an affordance model of technical instructions* (Rantakokko & Nuopponen, 2019) and *the phases of data handling in XR* (Rantakokko, 2022) as two essential elements of the TIER model and relating them to each other.

In the TIER model, the affordances of technical instructions are defined by Rantakokko and Nuopponen (2019) as accessing, finding, understanding, and relying on. Further on, the affordances are seen through the levels of rules, design, possibilities, and actualizing. This categorization offers a comprehensive view on technical instructions and the features they should have in order to fulfill their purpose of guiding a user of a technical device. These levels also enable viewing the design process from these main questions: 1) What laws, regulations, and principles are required to construct good guidance? 2) How should ideal technical instructions be designed? 3) How are designed affordances seen by the target user group? and 4) How will or will not these affordances be actualized in real use situations?

In a similar vein, the TIER model starts from the phases of data handling in XR as introduced by Rantakokko (2022): collection, processing, storage, transfer, combining, and presentation. This

process-based view on the features of XR increases understanding on how data is handled in XR and how XR works as a medium for technical instructions. It also enables for focus to be placed on the possibilities and challenges that XR offers for technical instructions.

To assist the designers of technical instructions in creating functional XR-based instructions for their target group, these two *essential elements* are combined into a model that serves as a practical tool for the thorough examination and analysis of the possibilities and challenges that XR brings in the process of designing technical instructions. Furthermore, the TIER model offers a way to relate the common and central features of XR to the affordances of technical instructions to gain an organized and comprehensive view on designing XR-based technical instructions. With the help of the TIER model, designers of technical instructions can, for example, deliberate on the most effective way to present instructions to users or consider whether an internet connection would be available at the location in which the instructions are used. If the internet connection is not reliable or always guaranteed, this can disable the affordance of accessing and, therefore, make entire XR-based instructions unusable if the instructions are only made available online.

The structure of this article is as follows. First, I briefly introduce the two previous studies upon which the current research is based. This is in order to explain how the affordances of technical instructions and phases of data handling in XR are understood in this study. Second, I present a methodological process of developing the TIER model. Next, I introduce the TIER model in detail and provide examples of how it can be used. Finally, I discuss the conclusions based on the findings of this research.

TWO ESSENTIAL ELEMENTS OF THE TIER MODEL

In the field of technical communication, there are many novel solutions for diverse challenges (see, e.g., Jones & Gouge, 2017 about wearable technologies; Tham, 2018 about wearables and IoT). These solutions utilize different technologies, accumulated research, and special knowledge. However, I focus strictly on XR-based technical instructions as well as the possibilities and challenges of XR. In the next two subsections, I introduce two *essential elements* of the TIER model: the

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affordances of technical instructions and the phases of data handling in XR.

Affordances of Technical Instructions

In this article, I view technical instructions through the concept of affordance. As Treem and Leonardi (2012, p. 46) stated, “[affordance] helps to explain why people using the same technology may engage in similar or disparate communication and work practices.” Furthermore, Treem and Leonardi (2012) explained that the concept of affordance is useful in research on relationships between new technologies and social practices. The concept of affordance was coined by Gibson (1979), explaining how animals perceive their environment through uses. For example, rather than a stone itself, a monkey perceives a series of functions that the stone enables (i.e., how the monkey can benefit from the stone and its interaction). Since then, the concept of affordance has been a subject of a wide-ranging discussion and a plethora of research ever since.

In the context of this research, affordances refer to the possible functionalities that objects, such as technical instructions, are designed to possess. Here, I also focus on how these possible functionalities may or may not be perceived, experienced, and actualized for the intended users and potentially unintended parties (e.g., cyber criminals). Furthermore, the affordances can be possible functionalities that are not intentionally designed to be actualized, or are inherent in the functionality, and thus able to be recognized and utilized. Based on the research of Rantakokko and Nuopponen (2019), the affordances of technical instructions are accessing, finding, understanding, and relying on. The tool mediating technical instructions to the user should be capable of delivering the designed affordances.

Based on Lanamäki, Thapa, and Stendal’s (2016, pp. 127–128) suggestion that affordances can be understood from four alternative stances, Rantakokko and Nuopponen (2019) took a broad perspective on the concept of affordance. In their view, each of the affordances of technical instructions can be seen at four levels: *the level of rules*, *the level of design*, *the level of possibilities*, and *the level of actualizing*. These levels are all present and valid at the same time, instead of being alternative, which makes the view broader. The affordances and their levels are illustrated in Figure 2.

The main point of this structure of affordances and their levels is that in order for technical instructions to be *accessed* when needed, they first must be designed and made available to the user. After accessing the instructions, the user should be able to easily *find* the necessary information. *Understanding* the information requires that it is well designed for the user, and it is expressed in an understandable way. To keep using technical instructions and operate based on the information received, the user must be able to *rely on* the instructions (Rantakokko & Nuopponen, 2019, pp. 58–61).

The four levels take the review of affordances deeper. *The level of rules* defines the necessary features that technical instructions should include according to laws, regulations, and principles of good guidance. *The level of design* is the level at which the desired affordances are established in technical instructions for the user from the perspective of the designers of technical instructions and their knowledge about the potential users. *The level of possibilities* focuses on the users and the affordances that the instructions offer for them. Finally, *the level of actualizing* defines actual situations, where affordances either will or will not be actualized.

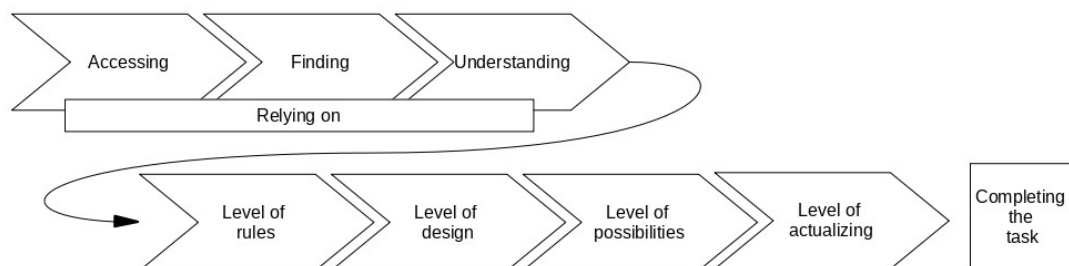


Figure 2. Rantakokko and Nuopponen's (2019) affordances of technical instructions and their levels

From the perspective of Rantakokko and Nuopponen (2019), the concept of affordances covers: 1) all the possible functionalities that technical instructions are required to include to fulfill their purpose; 2) all the possible functionalities that may be designed; 3) all the possible functionalities that the users see; and 4) all the possible functionalities that are actualized in real situations.

Rantakokko and Nuopponen's (2019) research is the initial point of departure for this article because it focuses on features of functional technical instructions. It offers a view on the possible functionalities of technical instructions that enable instructions to fulfill their purpose in guiding the use of a technological device. This study focuses on various types of technical instructions that can be delivered via the medium of XR. They can, for example, be assembly instructions, teaching instructions on how to use a technological product, or safety-related instructions of products that include real-time warnings.

The Phases of Data Handling in Extended Reality (XR)

Data and how it is handled in XR technology can be divided into two types. *Instruction data* refers to the technical instructions delivered by XR. *Collected data* covers the data collected by the XR equipment, i.e., the user's position and location (Rantakokko, 2022). In interactive XR-based instructions, these two types of data need to be combined. This occurs, for example, in order to enable the positioning of virtual elements in the context of the instructions – pinpointing optimal placement regarding the user's position and orientation. As such, there is nothing new in collecting information to design the instructions, but this study's focus

on the data that XR equipment, such as VR or AR glasses, collects from the users and their circumstances (personal, environment, context, etc.) is new.

In XR, the data is handled in several phases: collection, processing, storage, transfer, combining, and presentation (Rantakokko, 2022). These phases are illustrated in Figure 3.

Not only must data be *collected* and *processed* in order for XR equipment to operate, but it must also be *stored* somewhere for user access. Furthermore, it must be *transferred* to the user and sometimes for processing and storage as well. Finally, it must be *combined* with other data, such as virtual elements with the real environment, and it must be *presented* to the user. In Figure 3, the *transfer* phase is presented beneath other phases because it can be performed throughout.

Phases of data handling is the second essential element of this study as it offers an organized, process-based view on the features of XR, which enables analyzing them in relation to the features of technical instructions. With this combination, it is possible to analyze and describe the possibilities and challenges that XR brings in the process of designing technical instructions. In the next section, I introduce the methodology I used to combine these *starting points* in order to create the affordance model of Technical Instructions in Extended Reality, the TIER model.

METHODS

To combine the two essential elements of the TIER model, I followed an iterative process in which the existing empirical examples were placed into matrix tables until a point of saturation had been reached. Table 1 is an example of such a table, focusing on the

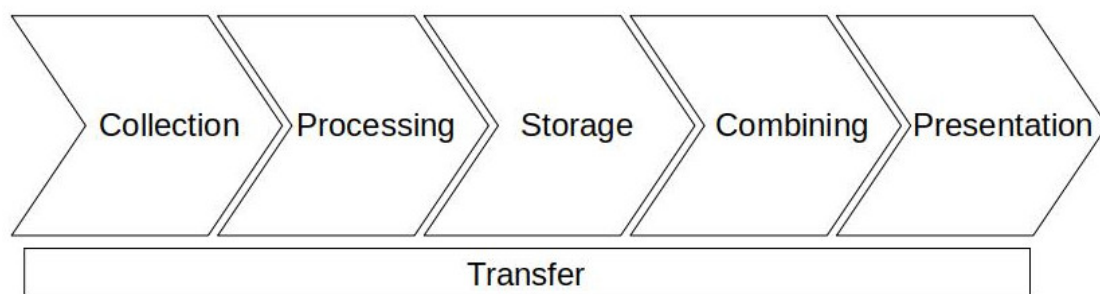


Figure 3. Phases of data handling in XR

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phase of data collection. The terms used in this table are explained in the Results section, where the complete table establishing the TIER model is introduced. Examples of the benefits are identified as user-friendly effects in Table 1. Table 1 also acknowledges the challenges faced during the data collection phase in XR, including privacy and security issues; these issues were also highlighted in previous research (Rantakokko, 2022).

In all of the matrix tables, like Table 1, the possibilities of XR-based technical instructions were related to the three-dimensional, real-time, and the interactive nature of XR. At the same time, privacy- and security-related issues were considered to be significant challenges due to continuous data collection by the software and devices.

RESULTS

I developed the TIER model to create a way to analyze the possibilities and challenges that XR as a medium brings to the process of designing technical instructions. The TIER model offers a way to approach this objective by enabling a holistic perspective on the process in two ways. First, the view of the affordances is comprehensive. The four levels of affordances of technical instructions take into account the aspects of rules, design, possibilities, and actualizing. Second, the TIER model views XR as a whole, focusing on the common features rather than differences between its types, such as VR and AR. While the model was constructed on the premise of empirical findings of existing research, the model itself, in its current state, has not yet been applied to further empirical studies.

The TIER model is especially designed for technical communication professionals who are planning to use XR technology in the delivery of technical instructions. The practical benefit of this model is that it offers an organized way to consider both the affordances of technical instructions and the process of XR data

handling, phase by phase. Designers of technical instructions may include their own requirements and goals in the matrix, choose one or several types of XR for different tasks, and ensure that all the necessary aspects are taken into consideration. The application of the TIER model can save a lot of time and money while avoiding potential mistakes. As stated, problems that may occur include privacy and security issues that emerge from constant data collection and the lack of user familiarity with the system, such as leakage of passwords or private conversations.

As Burova et al. (2020, p. 2) highlighted in relation to AR-based industrial instructions, “the development of industrial AR solutions should be iterative, with systematic testing, to identify the best strategies of information presentation and interaction for accessing the AR content.” Furthermore, Burova et al. (2020, p. 2) stated “errors in design may lead to dramatic consequences.” These points are valid for XR-based technical instructions as a whole and highlight the importance of an organized design process.

The basic elements of the TIER model are introduced in Figure 4. The levels of rules, design, possibilities, and actualizing are valid for all the affordances, even though, for clarity, they are listed only via the affordance of accessing.

The process of designing XR-based technical instructions are organized as follows:

- 1) Appraising valid laws, regulations, and recommendations for the type of instructions with each affordance (the level of rules)—for example, what is required for the instructions to be accessed;
- 2) Considering all the desired features and the ones that should be prevented, compared to affordances (level of design, focusing on technical instructions)—for example, what kind of safety-related guidelines are needed in the instructions;
- 3) Comparing the results with the phases of data handling in XR in detail to ensure that each phase

Table 1. The phase of data collection in XR in relation to the affordances of technical instructions

	Accessing	Finding	Understanding	Relying on
User-Friendly Effects	Warnings of critical situations in a work environment, situation-related instructions	Occurs	Occurs	Adding on safety and the quality of instructions
Privacy and Security Challenges	Sensitive data concerning the users, their surroundings, and bystanders	Occurs	Occurs	Input sanitization techniques

supports each affordance (level of design, focusing on XR as a medium for instructions)—for example, how the privacy and security issues are related to accessing data at every phase of the XR data handling; and

- 4) Testing that the users recognize the affordances present in the design (level of possibilities), and that the affordances can be actualized in real situations (level of actualizing)—for example, do the users understand phase by phase instructions in a maintenance task, and can they perform the task with the instructions.

The levels of possibilities and actualizing require empirical research because these levels are contingent on the users and real use situations. Because this study serves as an introduction to the TIER model. This article focuses on the first two levels of the model—rules and design. Still, the levels of possibilities and actualizing, defined earlier are important.

General Structure of the TIER Model

The basic structure of the TIER model is presented in Table 2. It is based on the affordances of technical instructions combined with the phases of XR data handling. The affordances of technical instructions (accessing, finding, understanding, and relying on) are listed in the table heading. The phases of the XR data handling (collection, processing, storage, transfer, combining, and presentation) are introduced in the first

column of the table. The table relates these aspects to each other by putting each phase of XR data handling in relation to every affordance of technical instructions as well as illustrates the impact that any phase of the XR data handling has on each affordance to being actualized for the users.

The terms used in the table, and how the concepts they represent are related to each other, are as follows:

Occurs:

When the affordance first emerges, it is marked as “occurs” in the table. The affordances of accessing, finding, and understanding occur when data is collected. The affordance of accessing also occurs for a new data set in the phase of combining.

Exists:

The affordance of relying on is marked as “exists” on every row. This is because the affordance can occur even before the XR-based technical instructions are designed, based on, for example, the users’ preconception about the technology of XR. Furthermore, relying on the instructions is a precondition throughout the process in order for the user to use the instructions in the first place. The effects of the phases of the XR data handling can be either positive or negative on the affordance of relying on, but if it does not exist, the technical instructions will probably not be used.

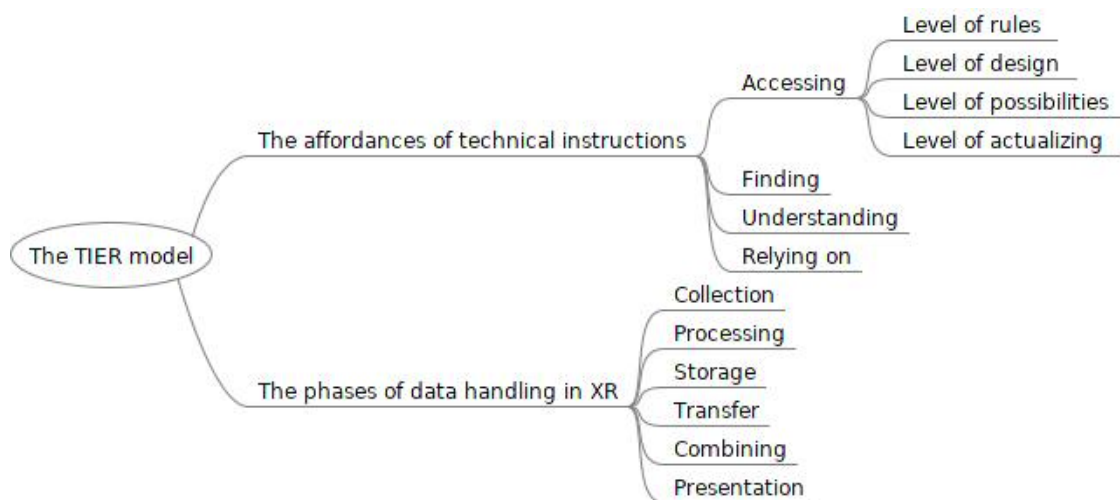


Figure 4. The basic elements of the TIER model

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Improves:

Some phases improve the probability for the affordance to be actualized. For example, when the data is collected, the affordance of accessing occurs, since, at that very moment, there is data to be accessed. However, for the XR equipment to operate, the data needs to be processed. This makes the affordance of accessing more realistic and even more so in the phase of presentation.

No effect:

Affordances of technical instructions, excluding the affordance of relying on, are temporally related to each other. This is because, for example, to be able to find the data in the instructions, the user must have already accessed the technical instructions, and, therefore, data storage has no significant effect on finding the data. Next, I introduce the TIER model in detail and include some examples that focus on the model's first two levels—the level of rules and the level of design.

Collection Phase of XR Data Handling

The first phase of the XR data handling is data collection. Data collection is an ongoing process because XR equipment needs to constantly collect data about the user and their surroundings to be able to

function (see, e.g., Piumsomboon et al., 2017, p. 36; Reilly et al., 2014, p. 275; de Guzman et al., 2019, pp. 8, 13). Table 3 introduces some examples of the various aspects that may be important to consider at this phase. Note: The numbered items within the subsequent tables in this article correspond to the numbered items in the narrative descriptions of the tables.

With the TIER model, this phase can be organized according to the respective levels.

Level of rules:

- 1) Considering the instructions and the target group, according to laws and regulations, what kind of data is allowed to be collected? For example, if the users are wearing the XR equipment, it may record all passersby, including their conversations, without their knowledge or consent awareness of the users or passersby. Or if the users log into an application or computer, their passwords may be recorded.
- 2) It may also be important to take measures to collect only the necessary and allowed data and solve the challenge regarding what to do with the rest. Furthermore, you may need to take measures to protect the data collected with, for example, input sanitization techniques.

Table 2. The TIER Model

The Phases of the XR Data Handling	The Affordances of Technical Instructions			
	Accessing	Finding	Understanding	Relying on
Collection	Occurs	Occurs	Occurs	Exists
Processing	Improves	Improves	Improves	Exists
Storage	Improves	No effect	No effect	Exists
Transfer	Improves	No effect	No effect	Exists
Combining	Occurs for a new data set	Improves	Improves	Exists
Presentation	Improves	Improves	Improves	Exists

Table 3. Data collection in the TIER model

	Accessing	Finding	Understanding	Relying on
Level of rules	1. What kinds of data are allowed to be collected?	Occurs	Occurs	2. How to collect only allowed data and protect it?
Level of design	3. What kinds of data need to be collected?	Occurs	Occurs	4. What kind of equipment can collect the needed data?

Level of design:

- 3) What kind of data needs to be collected, according to the purpose of the instructions? For example, should you track the user's eye gaze?
- 4) What kind of equipment can manage the collection of needed data in a reliable way? For example, if eye tracking is needed, which XR headsets enable this?

Regarding the affordance of accessing, data collection is the most important phase of the XR data handling. In order for access to take place, all the necessary data must first be collected. The instruction application could, for example, collect data from safety critical situations in a work environment, such as information regarding increased amounts of radiation or rising heat. In this way, safety-critical data is obtained, saved, and stored for retrieval and review at any time. The affordances of finding and understanding also occur at the phase of XR data handling, but data collection has no significant effect for them. Actions regarding data collection can affect the user's inclination preference to rely on XR-based technical instructions. If the user is, for example, given options to block some data from being collected, it may have a positive effect on relying on the instruction application. Thus, users can trust that not every word they say, every object they look at, or every physical or emotional reaction they have during the work task, is recorded and in the hands of the employer or an unknown outsider.

Processing Phase of XR Data Handling

After the data has been collected, it is then processed. This is vital for delivering outputs accurately, interactively, and in real-time, as de Guzman et al. (2019, p. 15) explained. Therefore, processing the data makes the affordance of accessing more realistic. In Table 4, there are some examples of considerations of this phase of XR data handling.

Level of rules:

- 1) According to laws and regulations, who is allowed to have access to data during processing? For example, if the data is processed on the servers of a third party.
- 2) Balancing with the guidance of good instructions and the limited space. For example, deciding which number of virtual elements is ideal without risking blocking the users' view of important objects in their environment, so that everything needed is easy to find.
- 3) Balancing the most easily understood objects with the required processing capacity of the equipment. For example, deciding on acceptable video quality so that the equipment can process data efficiently.
- 4) To make the XR-based instructions reliable for the users—how can it be ensured that processing the data is not too slow, causing delays? For example, does the equipment have enough processing capacity for the instructions designed?

Level of design:

- 5) What kinds of virtual objects are needed to be accessed by the users during the task at hand? For example, do they need real-time and interactive recognition of different parts of the technical device?
- 6) In which places can virtual objects be easily found? If real-time recognition of different parts is needed, how can they be situated in the user's view? Should the XR-based instructions recognize and point out the parts themselves, or would the recognition process demand the user to isolate and show different parts for them to be recognized? The latter could cause longer assembly processes and frustration, while the first could be less accurate.
- 7) How can understanding be supported in relation to data processing? For example, how could it be

Table 4. Data processing in the TIER model

	Accessing	Finding	Understanding	Relying on
Level of rules	1. Who can be given direct access to data during processing?	2. How can information be made easy to find?	3. How can instructions be designed so that they are easy to understand?	4. How can data processing be made fluent?
Level of design	5. What kind of virtual objects are needed to be accessed?	6. Where should those virtual elements be situated?	7. How can understanding be supported?	8. Where should the data be processed?

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ensured that the objects are presented in the right place and at the right time? Delays could mean that the application indicates the wrong part, which would make understanding difficult.

- 8) Considering the amount of data and the purpose, is it more reliable to process the data with the equipment or transfer it elsewhere to be processed? For example, is there too much data for the equipment to process, and if sent elsewhere, is the connection guaranteed?

The phase of data processing is a vital enabler of the possibilities of XR delivering technical instructions. This phase raises questions about what kinds of data are needed to be processed in order to make the desired functionalities possible and how this data can be balanced with limitations of the equipment. This matter has an effect on all the affordances. There may be a need to return to this phase during designing the phase of data presentation to ensure that the designed elements and the realities of processing support each other.

Storage Phase of XR Data Handling

The collected and processed data may be stored (see, e.g., Schmalstieg & Höllerer, 2016, p. 3). The phase of data storage allows for continuity; the instruction data and the relevant collected data are preserved for future needs. In Table 5, there are some examples of the issues to be considered at this phase of XR data handling.

Level of rules:

- 1) According to laws and regulations, what kinds of data are allowed to be stored? Often, unnecessary data about the users and their surroundings is forbidden to be stored.
- 2) How should the data be protected while it is stored to deny access from unauthorized parties? The data stored is vulnerable for attacks, and therefore, measures for protection are important to consider.

Level of design:

- 3) According to purpose, what kinds of data need to be stored? For example, the data collected when the XR equipment was used can include conversations. Some conversations could be necessary to store, such as direct instructions for a specific task, but some could be private or unnecessary.
- 4) Where should the data be stored? If there is a need for data storage solutions by a third party, it is important to consider that this party is reliable and has good protection for the data stored.

The phase of data storage is important for the continuity of using the instructions. Data storage provides an opportunity for access to the needed data whenever it is required. It, therefore, improves the possibility of the affordance of accessing to be actualized. This phase has no significant effect on the affordances of finding and understanding. However, for the affordance of relying on, it is important to take measures to protect the data and decide where to store it. If the users are not aware of what data related to them is stored and where, it could reduce their reliance on the XR-based instructions.

Transfer Phase of XR Data Handling

Data transfer may be needed for the purposes of processing or storage of the data. It is also needed for collaboration, for example, when using distant guidance via XR equipment (see, e.g., Reilly et al., 2014, p. 275; de Guzman et al., 2019, p. 30). Some examples are introduced in Table 6 to demonstrate how to use the TIER model in this phase of XR data handling.

Level of rules:

- 1) What instructions are required by laws and regulations to be available to the users at all times? For example, safety-related instructions are usually required.
- 2) How to make sure that the instructions are available when needed? For example, which instructions can

Table 5. Data storage in the TIER model

	Accessing	Finding	Understanding	Relying on
Level of rules	1. What kinds of data are allowed to be stored?	No effect	No effect	2. How should the data be protected?
Level of design	3. What kinds of data need to be stored?	No effect	No effect	4. Where should the data be stored?

be guaranteed via real-time data transfer only, and which instructions should be available despite the success of internet connection?

Level of design:

- 3) For what purpose is data transfer needed? For example, data processing and storage, or for collaborative use.
 - 4) How can the risk of interruptions and failures be minimized during data transfer? For instance, protecting data transfer, using encrypting, etc.
- Data transfer enables the processing and storage of the data in another location and collaboration in XR environments. At this phase, all needs for data transfer should be identified. Data transfer can improve the possibility of accessing the instructions by, for example, enabling distant guidance via XR equipment. However, if a good connection cannot be guaranteed at the location, XR-based instructions should be available offline as well. Transfer has no significant effect on the affordances of finding and understanding the data. When it comes to the affordance of relying on, fluently working instructions that are available when needed can enhance the affordance of relying on.

Combining Phase of XR Data Handling

Combining data is important for the basic functions of XR. The user's environment, location, position, and movements need to be combined without too much delay with virtual elements in order to enable the XR-based instructions to assist the user in a real-time and interactive manner (see, e.g., Graig, 2013, pp. 51–52). Data combining enables situation-related instructions by recognizing important objects in the user's environment and combining them with instructions on how to use these objects. These are new possibilities that other formats of technical instructions cannot offer. Therefore, there is a delay in laws, regulations, and guidance in relation to the evolving situation. Some examples of considerations at this phase of XR data handling are presented in Table 7.

Level of rules:

- 1) Data combining reopens the questions about data collection—after combining data, are there now new kinds of data sets that would not be allowed to be collected? For example, if it is necessary to measure the users' physical reactions to make sure they are not endangered in challenging conditions, and their eye gaze is measured as well, can there be a new set of data that reveals their reactions or emotions?

Table 6. Data transfer in the TIER model

	Accessing	Finding	Understanding	Relying on
Level of rules	1. What instructions are required to be available at all times?	No effect	No effect	2. How to ensure that the necessary instructions are available, even if the connection fails?
Level of design	3. For what purpose is transfer needed?	No effect	No effect	4. How to minimize the risk of interruptions and failures during the data transfer?

Table 7. Data combining in the TIER model

	Accessing	Finding	Understanding	Relying on
Level of rules	1. Is there access to new kinds of data sets that would not be allowed or recommended to be collected?	2. How can sensitive data be made difficult to find for unauthorized parties?	3. How can sensitive data be made difficult to understand for unauthorized parties?	4. Making sure that the users are aware of all kinds of data that is collected about them and how it is used
Level of design	5. What kinds of data sets need to be combined?	6. How can findability be increased through combining data?	7. How can understanding be increased through combining data?	8. Balancing benefits and risks

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- 2) How can sensitive data be made difficult to find for unauthorized parties? For example, XR equipment helps to prevent passersby from seeing log-in information when it is shown only with the device the user is wearing.
- 3) How can sensitive data be made difficult to understand for unauthorized parties? For example, encryption technologies could help to protect data even if an unauthorized party obtains access to it.
- 4) Informing users of all the central aspects concerning data combining and collection, such as what is collected and what kind of data sets can be formed with combining data, where is it stored, who has access to it, and how is it used, can enhance the possibility of relying on the XR as a medium for technical instructions.

Level of design:

- 5) What kind of data sets need to be combined for the user to access? For example, rising heat in the work conditions and possible actions that the user should take if this happens.
- 6) How can the instructions needed be rendered most easy to find with the help of data combining? For example, would tracking the user's eye movements help situate the data needed at the ideal spot?
- 7) How can data combining improve understanding? For example, would adding a virtual color-coding help realize the structure of a complicated technical device?
- 8) How can the risks and benefits of data combining be balanced? For example, combining data can add to accessing, finding, and understanding, but it can also add to the risks of private and sensitive data ending up in wrong hands.

Data combining enables and supports some of the most significant possibilities that XR can offer. At the same time, there is a risk with its ability to combine sensitive data to gain more knowledge about the user, an organization, or a bystander. It is important to give deep consideration of data collection from the aspect of data combining to make sure that there will not be any surprises regarding what kinds of leaked information data combining could lead to. Lastly, data combining influences every affordance.

Presentation Phase of XR Data Handling

Finally, the data is presented to the users, and the possibilities that all the previous phases offered become visible to the users (see, e.g., de Guzman et al., 2019, p. 18). The phase of data processing is also important to consider when designing data presentation. For example, it is relevant to realize the processing power of the equipment used and the possibilities and limitations to determine if there is a need for compromises in relation to what is desired in the phase of presentation. For instance, would increased privacy and security measures mean decreased exactness regarding the informational content and accuracy of the instructions? It is important to notice, that unlike any other instruction format, XR-based instructions can cause safety risks by blocking the users' view and thus making it impossible for them to see relevant objects from their environment. However, XR can decrease the risks by carefully designing the presentation to assist the user in noticing situations in their outside environment that need attention, such as rising heat in the device they are using or poor air quality. This highlights the importance of a carefully designed data presentation and the importance of how XR-based instructions differ from

Table 8. Data presentation in the TIER model

	Accessing	Finding	Understanding	Relying on
Level of rules	1. How can it be ensured that instructions can be accessed at all times?	2. How can it be ensured that the user will not be overloaded with too much data causing risks?	3. How can sensory overload be avoided?	4. How can the data presentation from hostile parties be prevented in order to keep it reliable?
Level of design	5. How to make instructions be made easy to access in all use cases?	6. How can instructions be made easy to find?	7. How can instructions be made easy to understand?	8. How can functional and uninterrupted presentation be guaranteed?

other instructional formats. Table 8 introduces examples of the considerations on the data presentation phase.

Level of rules:

- 1) How can access to the required instructions be ensured at all times? For example, making sure that the safety-related warnings are always available even if the connection fails.
- 2) Considering the nature of XR equipment, can the instructions be created in a non-disturbing way, while still making them easy to find? For example, avoiding long texts and blinking images.
- 3) How can sensory overload that could diminish understanding be avoided? For example, avoiding the use of many restless elements which can cause fatigue to the user's eyes.
- 4) How can the data presentation be protected from hostile parties in order to maintain reliability? For example, if the data is attacked at any point of XR data handling, the presentation could be rendered unreliable.

Level of design:

- 5) How can it be ensured that the needed instructions are easy to access at all times? For example, that the selected equipment is not only suitable for the work conditions, but also comfortable to use.
- 6) How can the instructions be made easy to find? For example, would visual, auditory, or tactile effects be most effective for the user to notice safety-related warnings most accurately, or possibly a combination of them?
- 7) What is the most understandable way to guide the user through the task at hand? For example, text, symbols, videos, etc.
- 8) How can the data presentation be made functional and uninterrupted? For example, designing instructions for different work phases to be activated when they are needed.

Data presentation is the visible part of technical instructions to the user. Well-functioning instructions give the needed data at the right time, but do not overload the user with unimportant data, blocking their view, or demanding their attention, unless it is absolutely crucial. Presentation makes accessing the instructions easy and realistic for the user. Well-designed presentation also has a significant effect on finding and understanding the instructions. Fluent,

functional, and uninterrupted presentation of the instructions enhances the chances that a user can actually rely on them.

CONCLUSIONS

In this article, I have introduced the TIER model, a tool that helps analyze the possibilities and challenges that XR brings to designing technical instructions. I introduced this model at a general and theoretical level with the help of examples of what to consider at each phase of the data handling in XR and in relation to every affordance.

I formed the TIER model by combining the two *essential elements of the TIER model*—the affordances of technical instructions and the phases of data handling in XR. I focused on the TIER model's first two levels, level of rules and level of design, out of its four. However, the TIER model's remaining two levels, level of possibilities and the level of actualizing, are important when testing the instructions to see which affordances the users notice and if the affordances are actualized in real use situations. This helps to improve the instructions designed, if needed.

The TIER model aims to benefit the designers of XR-based technical instructions by offering a tool for an organized design process that focuses both on the well-functioning technical instructions and the possibilities and challenges of XR as a medium for the instructions. By making sure that all the necessary aspects are taken into consideration, crucial mistakes and wasted resources could be spared. The strength of the TIER model is its versatility. It can be used to design the instructions as well as testing them, and in addition to the holistic view in XR, it can be used to view the details of different forms of XR related to technical instructions as well. To my knowledge, there are no other models that combine technical instructions and XR to increase the understanding of XR for mediating technical instructions. However, as XR becomes more common due to technological advances and reductions in cost, it is important for technical communicators to conduct more research in this area.

There are some limitations in this research. At this point, it covers only the levels of rules and design, and is, so far, only theoretical. It is yet to be tested with empirical research. However, the concept of affordance is based on the idea that the users can see and act on

Creating a Model for Developing and Evaluating Technical Instructions

various possible functionalities in the objects, despite of what they are planned for. This requires empirical studies that focus on the levels of possibilities and actualizing, making it important to test the TIER model in real design processes of technical instructions. It would also be fruitful to undertake studies of the effects of XR-based technical instructions, conducted with different methods but keeping a wide perspective of XR as a whole.

Many challenges, such as privacy and security risks, can be minimized by taking action during the early stages of XR-based technical instruction development. There are signs that privacy and security issues will increase in the future, when the technology becomes more ubiquitous and widespread, and these issues may be exacerbated with AI or data mining. Thus, more research is needed on the issues of privacy and security.

Furthermore, to fulfill its purpose in guiding technical communication professionals who plan to use XR as a tool to deliver technical instructions, research comparing different kinds of solutions and technologies with their benefits and deficits is needed.

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Affordance-based approach towards understanding user preconceptions of XR-based technical instructions

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Abstract: The TIER model is a designer tool for designing technical instructions for extended reality (XR) environments. This article reports a pilot study towards validating the model with user preconceptions towards XR-based technical instructions. Understanding preconceptions is important in user-centered design. The pilot test entails the presentation of instructions for a LEGO construction task via video and VR. The results indicate interest and willingness to test XR-based solution, but reluctance for regular use. The TIER model showed how the model supported the process of recognizing preconceptions and operated as a tool for an organized design process of XR-based technical instructions.

Keywords: technical instructions; extended reality; TIER model; affordance; user preconceptions; error handling

1. Introduction

Emerging technologies, such as artificial intelligence (AI), robotics, and extended reality (XR) systems, are becoming infiltrated into every area of society, including different fields of communication, such as journalism, marketing communications and technical communication. The term ‘technical instructions’ incorporates all instructions intended to guide and teach a user how to operate with a technical device (Markel 2012, p. 3). There are many ways to deliver these instructions to users, such as face-to-face guidance, video instructions, and printed manuals. XR is a relatively new medium for this purpose.

In contrast to traditional technical instructions, XR provides a three-dimensional environment that enables users to interact with objects and procedures in a more natural and intuitive manner. This allows for improved understanding and retention of information. XR has become an increasingly popular technology in recent years because of its potential to provide immersive and engaging experiences.

XR-based technical instructions are a relatively new phenomenon for most people. People’s reactions to any new object, including instructions and technical devices, varies and can sometimes be unpredictable (see, e.g., Kerchner & Ehlers 2016). Therefore, when designing XR-based technical instructions, focusing on the testing phase is crucial (see, i.e., Burova et al. 2020, p. 2).

This research aims to do exactly that by identifying how user preconceptions of XR as a medium for technical instructions can be identified in a systematic and organized manner. It also aims to investigate how these preconceptions can be taken into consideration in the design process of XR-based technical instructions. In other words, this research validates the testing process focusing on the influence of preconceptions.

The affordance model of Technical Instructions in Extended Reality, the TIER model, is designed to include all the phases of the design process of XR-based technical instructions. The model starts with the demands of laws and regulations, moving through the actual design process, towards the iterative phases of testing and re-designing. In order to illustrate how the TIER model functions, this research analyzed how users evaluate XR as a medium for technical instructions. The experimental approach involved participants first seeing the instructions in regular video form, and later in a simple XR-based form. The TIER model was applied to the analysis of the results. The model will be presented in more detail in the literature review.

Errors are part of the processes of human-systems. Identifying errors is therefore important in the context of design (see, i.e., Rasmussen & Vicente 1989), especially when focusing on the testing process, such as here in the current research. Therefore, in this research, the method for observing users actions in a situation of flawed instructions is achieved via a designed-in glitch (see, i.e., Dutke 1994).

This article begins with a literature review section, which introduces research concerning the user preconceptions about new technologies and XR-based solutions specifically. The materials and methods used in this research are introduced, including the TIER model and detailed information about the test designs and analyses of the results. The results section includes a report of how the research data reveals the preconceptions and impact of the designed-in glitch in relation to error handling. Finally, there is a discussion and conclusions are drawn from the pilot test of the TIER model, which seems to be a promising tool for testing phase.

2. Literature Review

The purpose of this study was to test a method to identify user preconceptions of XR as a mediator of technical instructions. The central concepts in the context of this research are introduced in the following order. First, the concept of XR is introduced. After that, the structure of the TIER model is discussed, followed by a brief introduction of how the concept of affordances is seen in the TIER model, and thus in this research. Finally, previous research concerning preconceptions related to this research is discussed.

XR is an umbrella term for realities that include virtual elements (see, i.e., Alizadehsalehi et al. 2020). These elements can be experienced via certain equipment, such as headsets or gloves (Fast-Berglund et al. 2018, p. 32). XR consists of virtual reality (VR) and mixed reality (MR). In Milgram and Kishino's reality-virtuality continuum, MR includes augmented reality (AR) and augmented virtuality (AV) (Milgram & Kishino 1994, p. 1321). The reality-virtuality continuum by the author (Rantakokko 2022a, p. 77), illustrated in Figure 1, has completed Milgram and Kishino's continuum by adding XR.

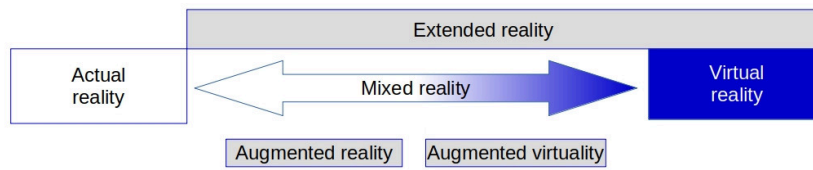


Figure 1. Reality-virtuality continuum (Rantakokko 2022a, p. 77)

Research concerning XR-based technical instructions mainly focuses on single tasks delivered with a single type of XR (see e.g., Tzimas et al. 2019; Doshi et al. 2017; Zauner et al. 2003; Hoedt et al. 2017). Despite many studies concerning XR-based technical instructions, research focusing on a holistic view on XR-based technical instructions seems to be lacking. Therefore, in this research, focus is placed on identifying user preconceptions during the testing process of any kind of technical instructions, delivered with any type or types of XR.

In this article, an affordance-based approach for testing a method to identify user preconceptions is introduced. In the context of this research, affordances are seen as: 1) designed features of technical instructions that aim to enable technical instructions to fulfill their purpose of guiding and assisting the users with technical devices; and 2) unintended features that are not designed but occur. The affordances may or may not become noticed by the users, and if noticed, they may or may not become actualized in real use situations.

Affordances and preconceptions are related. According to Churchill and Churchill (2005), the relationship entails preconceptions that influence how the user perceives the affordances of a technology. Therefore, the authors argue that understanding preconceptions may offer important information for intervention strategies to support the implementation of new technologies (ibid, p. 2).

The concept of affordance originates in Gibson's (1979) idea of how animals and humans can see unorthodox possible functionalities in certain objects. Whatever purposes and functionalities are determined by laws and regulations, and whatever the functionalities envisaged in XR-based technical instructions, the results can vary greatly when users engage with the instructions. Therefore, the concept of affordance provides the ground for the theoretical framework of this research: the affordance model of Technical Instructions in Extended Reality, the TIER model (Rantakokko 2022b).

The TIER model was created and introduced by the author (Rantakokko 2022b). It was developed to assist as a tool for an organized and comparable design of XR-based technical instructions. The model can be used in different ways and to

various degrees, depending on the type of the instructions, the organization, and the use context. It is, therefore, important to pilot test how the model functions as a tool. This is the focus of the present study. In this research, the TIER model is used in analysis of the results.

The TIER model combines central features of technical instructions and XR. The structure of the TIER model is illustrated in Figure 2, and explained in detail below. The sections of the TIER model used in this research are marked by red font.

In the TIER model, the central features of technical instructions are seen through an affordance lens. The affordances of technical instructions according to the TIER model are accessing, finding, understanding, and relying on. These affordances are the features that are required in order for the technical instructions to fulfill their purpose - guiding users of technical devices (Rantakokko 2022b). These affordances are temporally related to each other, as illustrated in Figure 3. First, the instructions need to be accessed. Next, the relevant information needs to be found among other information. After that, the information should be understood. An exception in the temporal connection is the affordance of relying on, which needs to be present at all times in order for the instructions to be used in the first place (Rantakokko & Nuopponen 2019; Rantakokko 2022b).

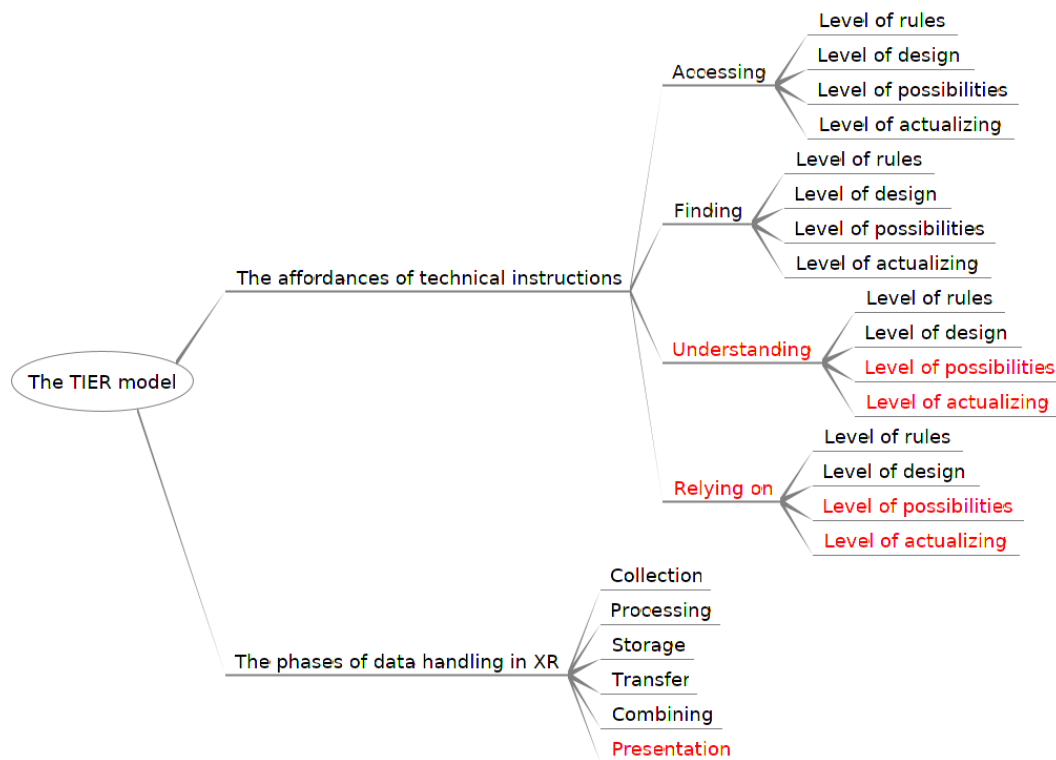


Figure 2. The TIER model (author).

The chosen affordances in focus in the current research are ‘understanding’ and ‘relying on’. This is because the set-up of the tests conducted already enabled accessing. Furthermore, the instructions designed for this research were simple, leaving the affordance of finding irrelevant.

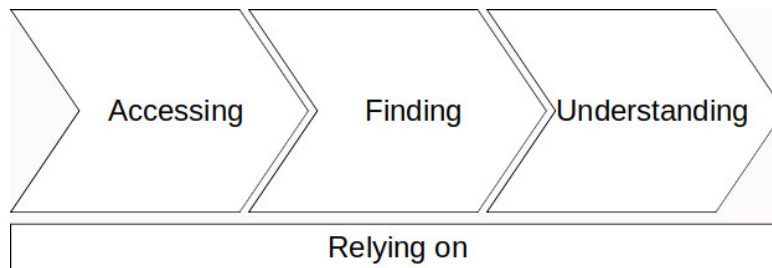


Figure 3. Temporal connection of the affordances of technical instructions (author).

The affordances are seen through four levels in the TIER model: rules, design, possibilities, and actualizing. The levels of affordances in the TIER model are based on and modified from the four alternative stances of affordances introduced by Lanamäki et al. (2016). Their stances are based on the critique considering the statement that Gibson’s (1979) idea excluded the temporal aspect on affordances – when the affordance occurs, and when it ends. In the TIER model, the levels are all present simultaneously. The level of rules includes the viewpoint pertaining to laws, regulations and principles which are required in order to design well-functioning technical instructions. The level of design focuses on the design process of technical instructions. The level of possibilities targets how the affordances included in technical instructions may or may not become noticed by users, and the level of actualizing is focused on whether or not the users act upon the affordances they have noticed. These levels are aimed especially in the testing process of XR-based technical instructions, and therefore are in focus in this research.

The central features of XR as a medium to deliver technical instructions are seen as phases in which the data flows in XR. With these phases as well, the TIER model includes temporal relations, as illustrated in Figure 4. The phases of the data handling process in XR include first collecting the data, then processing and storing it, possibly combining it with other data sets, and finally presenting the data (in this case the XR-based technical instructions) to the users. The data may be transferred at any time of this process. The focus is on the presentation phase, as it is the phase at which users can see current versions of the designed instructions.

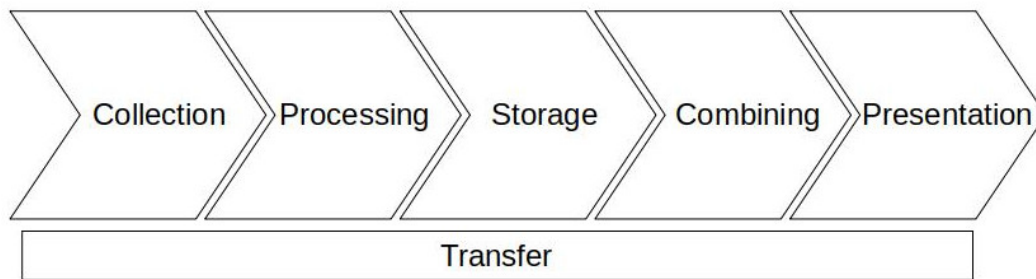


Figure 4. Temporal connection of the phases of data handling process in XR (Rantakokko 2022a, p. 82)

This research approaches how preconceptions may influence how technologies are perceived. Preconceptions form an important part of human predictive cognitive processing (see e.g., Clark 2013; Rasmussen & Vicente 1989). Preconceptions, in relation to expectations, serve to prepare humans for appropriate behavior according to what is anticipated as happening next (Clark 2013; Pearson et al. 2006; Tetlock 1999). These preconceptions can be positive, negative or mixed, and have strong emotional connections, in several levels (see e.g., Russel 2003; Marzilli et al. 2014). When it comes to new technology in general, or specifically XR as a medium for technical instructions, users' preconceptions affect their attitudes, which influence experiences in use situations (see i.e., Karagozlu et al. 2019; Law et al. 2009). Furthermore, they may even have correlations with specific technology skills (see, i.e., Marzilli et al. 2014). Therefore, it is important to map the preconceptions of the target user group and start involving users in the design process as early as possible. One way to identify preconceptions is via comparable tests before first use, and later at different phases of the design process and actual use situations (see i.e., Karagozlu et al. 2019), as is conducted in this research.

Positive experiences may improve user attitudes and thus increase motivation and curiosity toward learning via a new technology (see, i.e., Pearson et al. 2006; Karagozlu et al. 2019). Research concerning attitudes toward XR technology often focuses on the learning phase (see, i.e., e.g., Sirakaya & Kiliç Çakmak 2018; Sahin & Yilmaz 2020; Cheng & Tsai 2020; Huang & al. 2010). However, positive attitude may be caused by the 'wow-effect' of a new experience. For example, Wojciechowski and Cellary (2013) studied learners' attitudes towards AR-based learning environments called ARIES. They noted how the participants experienced usefulness and enjoyment, both influenced in a similar manner regarding their attitude toward using similar AR environments. They also noted that positive attitudes may fade with time when the users grow accustomed to the technology, unless the learners are offered more engaging content continuously (ibid., p. 583). Therefore, longer testing periods in the beginning may be the key to reducing

biased results. Over time, the feedback should stabilize enabling more accurate insight into the effects of the technology in the use context. This, in turn, is useful in a design process of XR-based technical instructions.

As user preconceptions have a significant influence on the usage of a new technology and its effectiveness, it is useful to map the preconceptions of the target user group before the first tests of XR-based solutions. Consequently, the research question in focus is: How can user preconceptions about new technology be identified through applying an organized and comparable method, the TIER model?

3. Materials and Methods

The purpose of this study was to test a method to identify users' preconceptions of XR as a mediator of technical instructions, thus focusing on the testing process. Accordingly, the method consists of analyzing and comparing the attitudes before and after a test situation of actual XR-based technical instructions based on the TIER model. Simultaneously, the TIER model was also pilot tested to analyze whether and to what degree it can be used in such tests.

The TIER model is embodied in the present paper as a case study (see, i.e., Heale & Twycross 2018). This is due to the fact that the TIER model is intended for the design process of specific XR-based technical instructions, within a particular context, and a more or less certain target user group. As the TIER model in this research is pilot tested, this research represents an exploratory case study. Exploratory case studies are mainly used in theory building, or for generating hypotheses for the purposes of later investigation (Baskarada 2014, p. 4). In other words, in the context of this research, the purpose is to test a method to see if it is functional. This form of testing is ideal before actual investment of resources into the design process of XR-based technical instructions.

3.1. Research Design

Two experimental tests were carried out, utilizing both remote and laboratory studies with observation, questionnaires, and interviews combined (see, i.e., Roto et al. 2019). The first test was conducted remotely. Remote testing is an established method, implemented numerous times for example in the context of usability testing (see i.e., Isohella 2018; Andreasen et al. 2007). The second test was conducted in a laboratory environment.

The instructions used in these tests were a basic, easily replicable, low-budget example in order to pilot test the TIER model and observe its capability as an organized and comparable method for the test process of XR-based technical instructions. The purpose was to show the users the same instructions via two different media, first in any typical form other than XR, and then in XR form. The type of XR used in this research was VR because this enabled the demonstration of the exact same instructions in both video and XR form. However, the method is usable with any type or types of XR, and is not limited to VR. As a comparison, any type of instructions that the target user group is used to, is functional.

Ethical considerations concerning this research focused on the safety of the participants, and their anonymity. As an immersive and persuasive technology, the use of XR raises ethical concerns (Pase 2012). In this research, participants were not pushed into self-tracking, which may sometimes be the case in work environments (Heikkilä et al. 2018). Instead, the only recorded actions were made via smart phone and stored locally. The recordings were deleted after transcription. Furthermore, the participants were told that they would be recorded and that the recordings would only be used in this research. They also were informed that their participation is completely voluntary, and that they are allowed to interrupt their participation to the test at any time, without having to explain.

Very limited background information about the participants was collected in research data: only participants' age and gender were asked and marked in the questionnaires, and their names and other identifiable information were not used. They were identified only by numbering in the research data. The tests were conducted as simply as possible because of the Covid-19 situation. In Test 1, contact was not needed at all. In Test 2, the participants were in contact only with the researcher, and corona masks were used. The participants were not present at the same time, and they were never told who the other participants were. The research design received approval from the ethics committee of the university in which the research was undertaken.

Test 1 was a preliminary test with video instructions to identify participants' preconceptions toward XR. Test 2 was a follow-up test, where participants were engaged with the same instructions delivered via XR equipment. The results of these two tests were then analyzed and compared by applying the TIER model. The test process is illustrated in Figure 5.

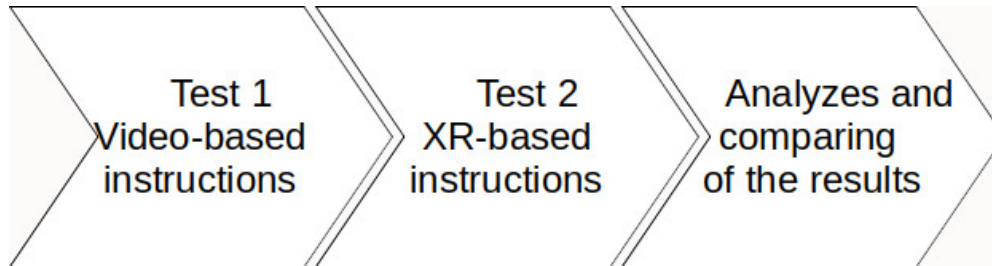


Figure 5. Test process (author).

In both tests, the participants were asked to evaluate the functionality of the instructions they received. In Test 1, the participants were asked if they believed that they would be able to complete the building task with the instructions. They were also asked to estimate if their evaluation would change if they would watch the instructions in XR form. In Test 2, the participants were instructed to complete the LEGO construction based on the instructions and evaluate the instructions' functionality based on that.

The design of the instructions was conducted in a minimalistic way that would allow for the observation of the instructions in both video and XR-based form. Therefore, the instructed task was chosen to be a simple LEGO construction, as shown in Figure 6. A non-complex form was selected because this study focused on the testing phase of XR-based technical instructions, and the user preconceptions of XR-based technical instructions. The instructions were designed to enable: 1) evaluating the functionality of the instructions they received; and 2) completing the task as well.



Figure 6. Screen shot of the LEGO construction from the instruction video (author).

The participants of these two tests received different set-ups to start the test. Test 1 was a remote test, so the participants received so-called starting images, which showed the blocks on the table. Each group had a slightly different starting image to see if that would make a difference in results. However, because of the limited number of participants, this comparison was omitted. In Test 2 the participants were present, and the actual blocks were situated on the table, thus forming the set-up for their test situation. Despite the differences, every version included 20 LEGO blocks (Figure 7), of which the task was to select the correct five blocks.

The participants were not told that one of the blocks in the set-up would be replaced with a different block compared to the instructions. The purpose of this glitch was to see if the users would notice such a minor flaw in the instructions they were supposed to evaluate. The glitch was included for the purposes of error handling, to make sure that the instructions would not be flawless, and the users' reactions caused by a glitch could be evaluated and analyzed (see, i.e., Dutke 1994).

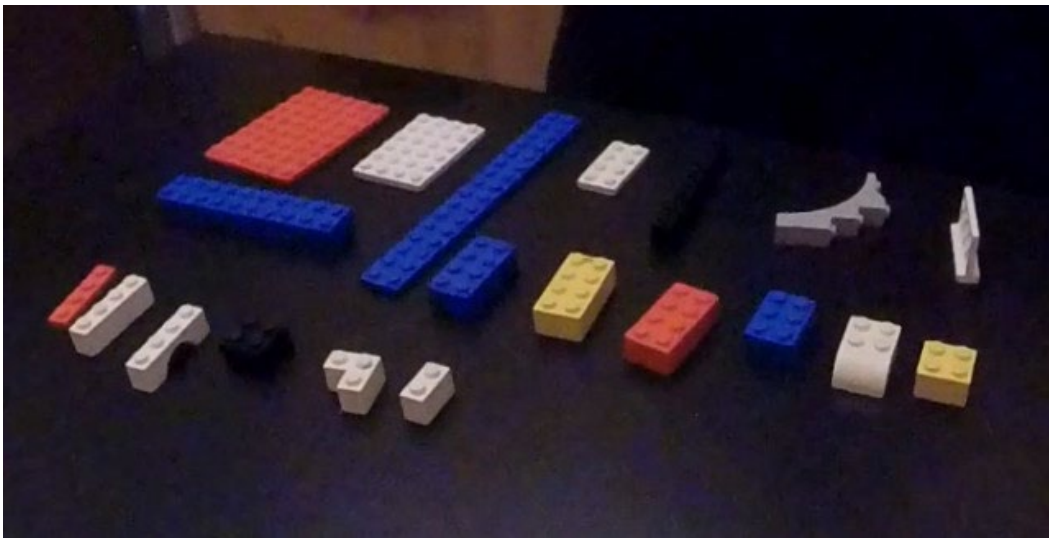


Figure 7. Placement of the blocks in the instructions (author).

The instructions guiding the operation of such devices need to be as accurate as possible. This is to ensure that no harm comes to the users, expensive machines, or work processes as a result of faulty instructions. While testing the test process of such instructions in an iterative, user-centered design process, it is therefore valuable to test also to what extent the users were able to notice glitches in the instructions, and if they mention them when they are noticed.

Furthermore, in the context of this research, it was estimated that the participants' willingness to report their perceptions may be limited for several reasons (see, i.e.,

Nederhof 1985; Ming et al. 2021; Callegaro 2008). The designed-in glitch therefore also served the purpose of identifying the participants' willingness to report if they noticed the glitch. It can be estimated that if they noticed the glitch and decided not to report it, they need to be encouraged to share their thoughts more openly, as unknown errors and estimations may additionally remain unreported. Next, the participants, materials, and instruments involved in the experiments are introduced.

Participants

The participants' experience levels with XR, as well as their age and gender were obtained from their answers to the questionnaires. Table 1 introduces the participants' background information, how they were recruited, and the number of groups they were divided into within each test. These variables are introduced in detail below.

Table 1. Background information of the participants (author).

Participants (information based on their answers in questionnaires):		
	Test 1: video-based instructions	Test 2: XR-based instructions
Number	7	4, of which two had participated in Test 2
Age	19–29	23–39
Gender	1 male, 6 female	4 female
Experience	Little or no experience with XR	Little or no experience with XR
Recruitment	Communication students	Convenience sampling and Test 2
Groups	3	2

In Test 1, there were seven participants. In Test 2, the Test group included two participants who had already participated in Test 1. Two new participants formed a Control group. Therefore, the number of unique participants was nine. One participant was male and eight were female, with the age range of 19 – 39. All of the participants were quite inexperienced with XR technology. It was apt to limit the number of participants because the research aimed to test a method instead of mapping actual preconceptions of a real target user group. In a pilot test, a small number of participants is reasonable in order to find out the usability of the method before investing more resources into the testing process (see, i.e., Etikan 2016; Kuniavsky 2003). Furthermore, as the approach was to conduct an easily replicable, low-budget example for a first test, or in this case a pilot test, it would not be generalizable with any number of participants, as the case was limited and did not include an iterative design process. Follow-up tests with more participants are needed in order to validate the preliminary results of this study, and to enable generalizability in case user group comparison is desired.

The participants in Test 1 were recruited via a call for participants at the researcher's university. The participants were students of technical communication. This ensured that they possessed interest in technical instructions and basic knowledge of what to expect in relation to these instructions. For Test 2, half of the participants were recruited among the participants of Test 1. Because only two were interested, possibly because of the Covid-19 situation at that time, two new participants were needed to form a control group of the same size. Convenience sampling was used to find these two participant groups (see, i.e., Cooper 2004).

It is important to note that when testing actual technical instructions, the participants should represent the real target user group. (Rousi 2014, p. 83) However, since in this research the focus is on the testing process of XR-based technical instructions instead of actual technical instructions with their own target group, the recruiting process focused on the participants' assumed interest in technical instructions in general.

Material

The material used was different in these tests, as introduced in Table 2 and explained below.

Table 2. Material used in the experiments (author).

Material:		
	Test 1: video-based instructions	Test 2: XR-based instructions
Guidance for test procedure:	Email instructions	Verbal instructions, printed instruction sheet on the procedure
Set-up:	A starting image, video-based instructions, conducted in privacy	LEGO blocks on the table, XR-based instructions, conducted with the presence of the researcher, recorded
Equipment:	Participants' own computers etc.	Oculus Quest VR
Task instructions:	Instructions in a regular video format, picture of the set up	Instructions in VR format

In the remote, video-based Test 1, the material was sent via email. It consisted of written guidance for the test procedure, starting images, and video-based instructions for the task. The participants used their own equipment to watch the instruction video.

In the laboratory Test 2, the material included verbal guidance and an instruction sheet for the test procedure, as well as XR-based instructions and LEGO blocks to complete the task. The instructions were delivered via Oculus Quest VR glasses.

These are basic VR glasses that are easy to use and have enough quality to make the XR experience satisfactory.

Before the tests, the task instructions were recorded with the Insta360 One X camera, and transformed into an approximately one-minute long 360-degree video. The participants could watch the video via a computer screen, or smartphone (Test 1), or via VR glasses (Test 2). The video was limited to showing the user how to construct a five-block LEGO shape step-by-step. It did not include speech or added virtual elements, such as arrows. The LEGO construction was intentionally abstract rather than, for example, a piece of furniture, so participants would be completely dependent on the instructions and would not be able to guess the intended result.

Instruments for Data Gathering

In Test 1, the instrument for data gathering was a questionnaire, which was offered via a survey and reporting software Webropol. In Test 2, data was collected in several ways. The questionnaire of this test was offered as a printed instruction sheet. Data was also collected via observation during the test situations, and interviews were undertaken after the test and questionnaires were completed. During the interview, the answers to the questionnaire and observations made during the test were reviewed. The participants were also encouraged to discuss anything they felt was important.

The questionnaires included the background information presented above in Table 1, and the participants' assessments of XR-based technical instructions. The questions aimed to identify if the users had understood the instructions, and if they had preconceptions toward XR technology before and after seeing the instructions in one type of XR. Preconceptions were approached from the perspective of reliance. That is, to which degree the participants would consider relying on the instructions given in XR form.

The questionnaires included a 5-point Likert scale, closed, and open questions. The questions with multiple choices were intended to acquire comparable data, while the open questions were intended to provide a deeper understanding of the participants' preconceptions, experiences, and assessments during the test situations. In both tests, the users were asked to evaluate how the instructions could work / worked with XR as a medium, and if it would be / was possible to complete the task with the assistance of these instructions. Next, I will introduce the procedures of each test in more detail.

3.1.1. Test 1

The participants in Test 1 were instructed to evaluate the instructions they received. The goal of Test 1 was to reveal users' preconceptions about XR as a potential medium for technical instructions. Even though the participants had no to little experience of XR, they were familiar with the terms 'VR' and 'AR'. Possible preconceptions were mapped by allowing the users to watch an instruction video. The participants were then asked in a questionnaire how they estimated the usefulness of the instructions. Their possible preconceptions were targeted with questions related to their evaluation of the instructions they saw, and how they would imagine the result would have been with XR-based instructions instead. They were also asked as to whether they would rather use the type of instructions they saw, or XR-based instructions. As they yet had not tested XR-based instructions, their evaluations were assumed to be in relation with their possible preconceptions. The test was also designed to collect information about the possibilities that the users noticed if they did not engage with the task itself, but instead only watched the video-based instructions.

Twelve participants volunteered to participate in Test 1 and were divided into three groups of four participants. However, after receiving the research material, only seven out of 12 volunteers actually participated. The answers came from three participants of Group 1, one participant of Group 2, and three participants of Group 3.

The participants received an email explaining the instructions, including links to the instruction video and a Webropol questionnaire. Participants also received a starting image in which 20 LEGO blocks were placed on a table. The designed-in glitch was in the form of an inconsistently colored LEGO block within the ensembles, as seen circled in Figure 8. The starting images were different for each group (see Figure 8) to determine if there was any effect on the participants' assessments. It was assumed that the designed-in glitch may be easier to notice if the order of blocks would be identical to the instruction video, and that it would be most difficult to spot if the blocks would be randomly placed.

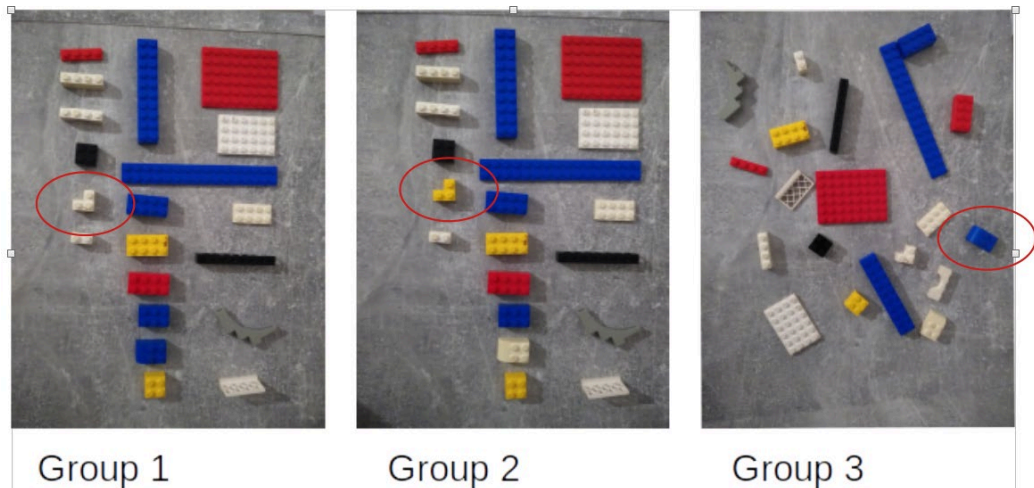


Figure 8. Starting images in Test 1 (author).

The instruction video was presented as a regular video to be watched on the participants' own computers or smart phones. The participants' task was to evaluate the instructions and estimate if they believed that they would be able to complete the building task with the instructions. They were also asked to estimate if their evaluation would have changed if they would have seen the instructions in XR-based form.

3.1.2. Test 2

The goal in Test 2 was to see how the preconceptions would change if the participants saw the same instructions in XR form instead of regular video form, while trying to complete the task in practice. The test was conducted at the VME Interaction Design Environment. Two of the participants were new, and two had participated in Test 1. The new participants (Control group) offered a comparison in relation to those who had already been exposed to the video instructions (Test group – participants from Test 1). The two participants of the Test group who had evaluated the instructions earlier in regular video form, were now able to experience XR-based instructions, while actually engaging with the task.

The participants of the Test group received the same instructions and set-up as they had in Test 1. However, this time they had access to VR glasses and were asked to complete the building task. All of the participants were informed that their task would be to watch VR-based instructions and then build a LEGO structure according to the instructions received. They then needed to evaluate the functionality of the instructions. They were guided to read the instruction sheet and asked if they needed further information. After that, the participants received VR glasses and were assisted in their set-up and usage. When ready, they were free

to engage with the task. They were informed that they would be allowed to stop the test at any time but would not then be allowed to continue later.

The participants were allowed to watch the instructions as many times as they felt necessary. They were observed, and the test situations were recorded, as were the interviews. The test design included non-participant observation and therefore the participants were instructed not to engage with the observer before the test was over and the questionnaire complete (see, i.e., Rizzo 2011). However, all participants did interact with the researcher. Therefore, it was decided to allow this instead of interrupting the test. The relevant part of the observation remained non-participatory and the users were only assisted with their use of the equipment, not the task itself. The participants were asked to complete the questionnaires as soon as they had finished the task, prior to the interview. Interview questions focused on what happened during the test, and what the participant had answered in the questionnaire. For example, “what did you mean by this,” or “how did you experience that”?

Observing was conducted by sitting in the background and making notes, while a smart phone was situated in front of the participants recording the test situation. The recordings were transcribed by watching the recordings and marking down every action and comment, in addition to adding timestamps.

3.2. Data Analysis

The data analysis was conducted with the TIER model. The analysis began by time stamping and transcribing the recordings of Test 1. The transcriptions were then thoroughly examined several times, and irrelevant observations were left out. Irrelevant observations included notes such as participant rubbing their nose etc. Next, the relevant observations from the transcriptions were combined with the answers of the questionnaires of both tests, and interviews of Test 1 in matrix tables.

As the TIER model is based on affordances, and the chosen affordances in this research were the affordances of understanding and relying on, the analyses continued by categorizing each single note under the affordance it was related to. For example, the questionnaire included the following question, “Do you believe that you would have experienced the same reliability of the instructions if they had been presented through VR glasses?” The answers to this question give insight on willingness to use XR technology, which it is assumed to reflect the reliance towards XR technology.

The analysis considered the affordances noticed by the participants. The approach permitted an organized comparison of the results and what they indicate regarding the affordances featured in the tests. The answers were compared between tests. The answers of the two participants who had participated in both Tests 1 and 2 were further analyzed to review if their assessments changed when they tried to complete the task with the XR equipment. Below, the results of the analysis are introduced.

4. Results

The research question of this paper is: How can user preconceptions about new technology be identified through applying an organized and comparable method, the TIER model? The answer to this question was sought via two experimental tests based on the same technical instructions displayed in video form versus XR-based form. The aim was to ascertain which affordances participants noticed while watching the instructions and what actions they took while trying to complete the given task when the instructions were flawed. Next, the results of the tests are introduced separately.

4.1. Results of Test 1

In Test 1, the participants were shown technical instructions in video form, and they were asked to estimate the instructions, and how they predicted that the instructions would work in XR form. The purpose was to identify the degree to which the participants noticed the designed affordances and how they estimated the functionality of the instructions in XR form to identify their preconceptions towards this technology. The answers to the questionnaire represent either the affordance of 'understanding', or the affordance of 'relying on'. Since none of the participants had much experience with XR, their answers about preferences and how they estimated that they would have evaluated VR-based instructions reflect their reliance on XR. It was assumed that if they had previous experience, this would influence their preconceptions (see, i.e., Karagozlu et al. 2019).

In combination with Test 2, it also facilitates a comparison of how the observation of affordances changes when the task is actually attempted with the assistance of the XR-based instructions. Key observations from Test 1 are assembled in Table 3 according to their respective affordances. The answers of each group are presented in separate columns, and the fourth column summarizes all the answers.

Table 3. Key observations from Test 1, related to the affordance of understanding (author).

Group 1	Group 2	Group 3	All (7)
Affordance of understanding			
<i>Following these instructions, do you believe you would have been able to complete the task?</i>			
Yes (3)	Yes (1)	Yes (3)	Yes (100 %)
<i>Did you notice that there was a glitch in the instructions and that one LEGO block was incorrectly colored?</i>			
Yes (2), No (1)	No (1)	No (3)	Yes (29 %), No (71 %)
<i>Would you still have completed the task despite the glitch, using another block?</i>			
Yes (2), No (1)	Yes (1)	Yes (2), No (1)	Yes (71 %), No (29 %)
<i>Did you follow the execution order mentioned in the test instructions?</i>			
Yes (3)	Yes (1)	Yes (3)	Yes (100 %)
<i>Did you find the instructions understandable?</i>			
Very (1), Relatively (2)	Relatively (1)	Very (2), Relatively (1)	Very (43 %), Relatively (57 %)

The experienced understanding of these instructions was high, while the actual understanding was questionable. All the participants in Test 1 stated that they would have been able to complete the task with the instructions they viewed. However, only two of seven participants reported noticing the glitch. Most participants (five out of seven) reported that they would have completed the task despite the glitch, while two thought they would not have. They all mentioned that they followed the instructed order. However, this could not be verified by the researcher. With actual instructions to be designed, therefore, specific attention towards colors would be needed. It would also be important to observe if the right order of the actions is really followed. Next, in Table 4, key observations related to the affordance of relying on are introduced and explained below.

The indicated reliance on XR-based instructions was relatively low among the participants. Five out of seven were willing to use XR-based technology in work or studies. However, none of the participants reported that they would have chosen XR-based instructions if they had other options at their disposal. Instead, they stated that they preferred video instructions. In this test, the instructions were in a video format, which may have influenced their answers. One participant remarked that VR-based instructions would be the best alternative for a more complex task. Overall, participants seemed to have some negative preconceptions about the technology and the use of it. In the case of actual XR-based technical instructions and negative preconceptions of the real target user group, it would be important to identify these preconceptions and work towards improving them during the design process of XR-based technical instructions.

Table 4. Key observations from Test 1, related to the affordance of relying on (author).

Group 1	Group 2	Group 3	All (7)
Affordance of relying on			
<i>Would you like to use VR / MR technology in your work or studies if you had the opportunity?</i>			
Yes (2), No (1)	Yes (1)	Yes (2), No (1)	Yes (71 %), No, (29 %)
<i>Would you rather use paper instructions, potentially with pictures assisting the instructions, or VR instructions like these?</i>			
Video (3)	Video (1)	Video (3)	Video (100 %)
<i>Would you rather have watched these instructions in VR form, or regular video like in this instance?</i>			
Video (3)	Video (1)	Video (3)	Video (100 %)
<i>If you think of a more complex task, for example a LEGO construction of 50 pieces, what type of instructions would you choose for that task?</i>			
Paper (2), Video (1)	VR (1)	Paper (1), Video (2)	Paper (43 %), Video (43 %), VR (14 %)
<i>Did you find the instructions reliable? (Estimate as a whole both the content of the instructions and the technology used (VR glasses).</i>			
Relatively (3)	Very (1)	Very (1), Relatively (1), Not reliable nor unreliable (1)	Very (29 %), Relatively (57 %), Not reliable nor unreliable (14 %)
<i>Do you believe that you would have estimated the reliability the same if the instructions were mediated via VR glasses?</i>			
Yes (2), No (1)	Yes (1)	No (3)	Yes (43 %), No (57 %)
<i>As a whole, did you find the instructions functional, or did they have flaws?</i>			
Flaws (3)	Flaws (1)	Flaws (2), Functional (1)	Flaws (86 %), Functional (14 %)
<i>In order to function, VR and MR devices constantly collect information about their user's position, location, and data on their environment. If you were to use VR or MR glasses in your work, what thoughts does this continuous data collection evoke in you?</i>			
Worried on my own behalf (2), Would not worry on my own behalf (1), Would not worry about bystanders (1)	Would not worry on my own behalf (1), Would not worry about bystanders (1)	Worried on my own behalf (2), Would not worry on my own behalf (1)	Worried on my own behalf (57 %), Would not worry on my own behalf (43 %), Would not worry about bystanders (29 %)

The participants of Test 1 evaluated the reliance of these instructions as quite high. Four out of seven thought that they would not have evaluated the reliability the same if they had seen the instructions in VR-based form. Only one stated that the instructions did not have flaws, while six out of seven reported they did. Participants seemed to be quite active in giving feedback on the instructions and their quality. This is useful for an iterative development process of the instructions. The users should be encouraged to continue giving feedback also with later versions, and while actually using the instructions.

The final question in the questionnaire of Test 1 concerned the XR technology continuously collecting data on the users and their surroundings, and if the participants were worried about their own security or that of bystanders. The majority of the participants (57 %) were concerned about their own privacy while 43 % were not. Two participants declared they were not concerned about bystanders' privacy. However, five did not answer, and their results do not tell if they would or would not be worried, since they marked neither of the options. Concerns about privacy and security were divided. This indicates that the users need more information about the issues related to XR-based technical instructions. It is important that they realize the risks. This would help motivating avoidance and minimizing threats while utilizing the tools.

4.2. Results of Test 2

In Test 2, the participants engaged with the task with XR-based instructions (in VR form), and gave their evaluations based on their experience of the task and equipment.

The two participants from Test 1 formed the Test group. Neither of them had previous experience in using VR glasses. Two new participants formed a Control group. These participants had tried XR glasses a few times prior to the experiment. All the participants were female, aged 22-39. Table 5 presents the combined key notes.

Table 5. Key notes from Test 2 related to the affordance of understanding (author).

Test group	Control group
Affordance of understanding	
<i>Did you find the instructions understandable?</i>	
Very easy to understand (both)	Very easy to understand (both)
<i>As a whole, did you find the instructions functional, or did they have flaws?</i>	
Flawed with a mention of the designed-in glitch, Functional	Functional (both)
<i>Did you succeed in building the LEGO construction with the instructions?</i>	
Yes (both)	Yes (both)

Understanding was reported to be very easy by all of the participants. Only one participant in the Test group reported flaws by mentioning the block of a different color (designed-in glitch). Others answered that the instructions were functional. This was despite the fact that the instructions were not indeed functional because the designed-in glitch made it impossible to build the exact same structure as

presented in the video/XR. Despite this, each participant answered that they successfully completed the task with the help of the instructions, including the participant who mentioned the glitch. Most of the participants built almost the same form, just replacing the final block with a similar block of a different color. Next, the answers related to the affordance of relying on are introduced in Table 6, and explained below.

The estimated reliance was high after Test 2. However, most of the participants would rather use another type of instructions over XR-based instructions in different tasks. The participants were interested in XR technology and in using it in general. Their willingness to choose more traditional types of instructions in specific questions may have much to do with their experience with the XR-based instructions of these specific tests. Only one participant mentioned being reluctant to use XR on a regular bases because of negative experiences in the past. This included the onset of a headache and vertigo. It is important to try to make first experiences pleasant and interesting if there is an intention to use a new medium more often. Furthermore, efforts should be made to increase the sense of ‘relying on’, while avoiding contributing to negative attitudes towards a new medium and the changes it requires.

Table 6. Key notes from Test 2 related to the affordance of relying on (author).

Control group	Test group
Affordance of relying on	
<i>Compared to traditional paper instructions, possibly with pictures assisting, would you rather have used paper instructions or VR instructions like these?</i>	
Rather VR instructions, Rather paper	Rather paper (both)
<i>Compared to Youtube instruction videos, would you rather have used video instructions or VR instructions like these?</i>	
Rather VR, Rather video	Rather video (both)
<i>If you think of a more complex task, for example, a LEGO construction of 50 pieces, what type of instructions would you rather use?</i>	
Paper (both)	Video, paper / video
<i>Did you find the instructions reliable? (To include both the content of the instructions and the VR glasses technology used).</i>	
Relatively reliable (both)	Relatively reliable, Very reliable

However, there may be a conflict here. On the one hand, if the design process is iterative, the early versions may include flaws. If the users have their first experiences with very flawed versions, their experience may be negative. Bad experiences may have a negative impact on their attitudes towards the new technology (see, i.e., Funk et al. 2015). On the other hand, the absence of users in the early phases of the design process may result in bad design choices before the

first tests, and later design phases. One solution to this conflict may be in including elements of a co-design process, with the focus of user experiences. When the users are involved from the very beginning in co-designing, their innovations can be integrated and their experiences, even negative ones, can lead to better design (see, i.e., Lowell & Morris 2019).

4.3. Comparison

The answers of the participants of the Test group remained largely unchanged compared to their answers in Test 1. Yet, there were small deviations to some answers, such as on preferred types of instructions. Instructions utilizing VR were seen as slightly more understandable and slightly less reliable after Test 2, in comparison to after Test 1. However, the changes are minor and may be due to a normal variation in answers given in different circumstances. Via further investigation the effects may appear stronger, by testing the activities with more complex instructions as well as with a larger sample size. In the iterative design process of actual XR-based instructions, continuity is important (see, i.e., Rizzo 2011). Noticing how the attitudes of the users do or do not change over time will be helpful in design work.

5. Discussion and Conclusions

This research aimed to test a method to identify users' preconceptions about XR-based technical instructions with an organized and comparable method. The purpose was to conduct two empirical tests and to analyze their results using the TIER model as a tool. The tests included simple technical instructions which were watched in regular video form in Test 1, and via VR equipment in Test 2. The participants' task in Test 1 was to evaluate these instructions and estimate how they would function in XR form. They were also asked if they thought they would be able to complete the test with the assistance of instructions. The task in Test 2 was to watch the instructions in VR-based form and to try to complete the task of building the LEGO structure, and then evaluate the instructions. The research data consisted of the answers in the questionnaires in both tests, interviews in Test 2, and the transcriptions of the recordings of the test situations in Test 2.

Test 1 indicated some negative preconceptions about XR as a medium for technical instructions. Test 2 indicated only marginal development of preconceptions. The pilot test of the TIER model indicated its usefulness in a test process. Therefore, one way to identify the preconceptions of the users is with an iterative test process with the assistance of the TIER model. However, more research is needed.

The main limitation of this research was that the instructions were simple, and therefore, also the variables in focus were few and without continuity. Furthermore, the test groups were small. As the purpose was to pilot test the method, the tests were possible despite the limited number of participants. However, with the limited amount of participants there is no possibility for generalizations. Therefore, also the intended comparison of the differences that alternative starting images may have caused was omitted. Larger follow-up tests are required to add these aspects. As the pilot test indicated the functionality of the TIER model as a tool for such tests, follow-up tests to validate the results are now reasonable to carry out.

Methods for data gathering in Test 1 were limited. To identify the cause of differences between the groups would have required interviews. Test 1 did not include interviews because of the Covid-19 situation. However, for the purposes of this study, interviews were not crucial. In an actual design process of XR-based technical instructions, interviews would have been important to follow.

The current research focused on pilot testing the TIER model for the purpose of an organized testing process of XR-based technical instructions. Despite the limitations mentioned above, in the pilot test, the TIER model seemed promising in providing the frame and body for conducting and analyzing the test process of XR-based technical instructions. It seems that the TIER model enables comparability, which is called for in studies concerning XR (see, i.e., Funk et al. 2015). The matrix tables of the TIER model make it possible to compare how the designed affordances become noticed and actualized with different users in various use situations. It also enables insight into what types of anomalies may occur during test situations. The comparison is possible with iterative design phases of the same XR-based instructions, as well as by comparing different types of solutions. However, more tests would be needed to confirm this. According to this experimental study, applying the TIER model seemed capable in assisting the analyses of the testing process and the results.

In future research, the next step could be, for example, a larger test conducted together with professionals of technical communication, using real technical instructions. This test could be conducted with any aspect or combination of the TIER model. If it still seems valid, then the TIER model could be tested with a whole design process, from the beginning to the ready technical instructions. These tests should cover different areas, such as privacy and security issues, different target user groups, and different tasks and work phases, as well as environments. These may be conducted from different angles, with more defined variables.

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XR-based technical instructions in organized testing: User behaviour and design performance

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Extended reality (XR) is changing the way humans interact with information. Developers are currently experiencing a need to understand more about the use and design of XR-delivered information. Humans are active agents within human-technology interaction. There is a need to systematically study how human agency affects the nature of XR content and how this knowledge can be applied within the content design process. The present article focuses on the context of an iterative co-design process for XR-based technical instructions. The research question is: In what ways can technology-based user behavior inform the design of XR-based technical instructions? Studies exist concerning XR-based technical instructions, yet the comparability of these studies is low. User characteristics among other variables influence the results of using XR-based technical instructions. The method comprises two experimental studies that aimed to identify how users notice and act upon or ignore both designed and unintended features of XR-based technical instructions. A framework for systematically testing XR-based technical instructions was developed and applied. The results indicate that verbal evaluations of the XR-based technical instructions may not be reliable. A systematic mixed method test process is crucial transitioning the design of technical instructions to a new medium. Conclusion: There is a need for a systematic method to test how users notice and act upon the intended features of XR-based instructions. The specific target users need to be involved in this iterative process.

Keywords: Technical instructions, Extended reality, Virtual reality, User-centered design, TIER model

1. Introduction

Radical changes are occurring in contemporary society, many of which are influenced by exponential technological developments. The past three years alone have seen work environments change from central offices to remote and hybrid work settings, and Generative Artificial Intelligence (AI) sending knowledge workers into existential dilemma (see e.g., Shukla 2023). The rhetoric of the Metaverse (virtual reality (VR) and extended reality (XR) has taken a stronghold on revolutionizing the ways in which we experience space, time, each other, and reality itself (see e.g., Brambilla Hall & Baier-Lentz 2022). With this in mind, it should not be surprising that these technological game-changers may provide numerous pragmatic advantages when re-thinking traditional forms of information presentation. One area of information presentation and design with a reputation for being awkward to use is that of technical instructions. Arguably, instructions (manuals), and particularly technical instructions, while intended to assist users and consumers, have been the bane of object engagement, assembly, and understanding particularly in the age of personal computing and self-assembly of products (see e.g., Novick & Ward 2006; Woodson 1995).

Professionals such as Marrazzo (2018) explain the Active Users Paradox, in which users optimize the time it takes to achieve use goals through short-cutting instruction engagement. Marrazzo highlights the need to incorporate alternate learning styles in the instruction design as well as minimize reading time by emphasizing affordances, or pictorial information showing what can be done with what component to achieve specific results. For this reason, the area of XR shows great promise via its immediacy, proximity, and fidelity in the domain of technical instructions (Fiorentino et al. 2014).

1.1 XR and technical instructions

XR has increasingly been used to deliver technical instructions in industrial contexts (Gattullo et al., 2019; Vanneste et al. 2020). The ability to offer 3D, situation-related, and interactive instructions can significantly improve the efficiency of learning about and operating devices (Doolani et al. 2020). XR is an umbrella term that refers to 3D, interactive and real-time environments that include artificial, virtual elements (see, e.g., Fast-Berglund et al. 2018, p. 32). XR consists of virtual reality (VR) and mixed reality (MR). MR can be further divided into augmented reality (AR) and augmented virtuality (AV) (Milgram and Kishino, 1994). However, technological and social barriers have slowed XR from becoming widespread. These barriers are now starting to be resolved in various applications (Fast-Berglund et al. 2018, pp. 31–32). Yet, technological maturity and mass

industrial uptake has taken some time. With this said, there have been several more advanced companies that have been forerunners in developing and utilizing XR for technical instructions, such as Mobidev, XRMeet, TechSee, WhaTech, and EDIIIE to name some. EDIIIE's³ applications for instance, extend to the fields of aviation, automotive, education, military, consumer goods, aerospace, and entertainment. In particular, the application of XR in instructional design has been studied more in the fields of education (see, e.g., Ding et al. 2020; Etambakonga 2021) and medical services (see, e.g., Bao & Hurriyet 2021; Ara et al. 2021).

1.2 XR-enabled technical instructions - the missing links

The public knowledge of business customers in this area is not extensive. Thus, insight into the role of users within the development process, how users experience XR-enabled technical instructions (in industrial settings and otherwise), and how the systems have been iteratively developed based on user feedback is not widely available. This supports motivation for engaging in systematic user-centered inquiry of XR-based technical instruction design processes. For, in order to design for optimal fluency of information presentation, comprehension and application, there is the need to understand more about how the behavior and specifications of users impact the effectiveness of the instructions themselves. In moments of human-technology interaction (HTI), this behavior is often in relation to the technology. Meaning that there is a true interactive process between what is presented in the XR technology, how people receive and respond to the information, and how in turn human responses impact the instruction design.

While there are numerous usability testing and design methods in circulation, no extensive model has been designed to date, with the specific purpose of analyzing this interactional reactive-proactive process of humans in XR-based technical instruction use. The affordance model of technical instructions in extended reality (TIER) was developed to assist in the dissection of human-technical components involved in XR-based instruction design. The research question is: in what ways can technology-based user behavior inform the design of XR-based technical instructions? By technology-based the authors refer to behavior that is specifically influenced by the technology, its affordances and limitations. For instance, while wearing VR glasses users are not encouraged to physically move around physical space. Affordances of the XR displays such as 3D details and interactivity with the virtual environment might encourage users to explore in ways they would not have necessarily imagined in relation to previous paper or video versions of instructions. This renders the testing phase within the design process particularly

³ See more at: <https://www.ediie.com/cases/>

important, especially from the perspective of ascertaining how humans behave when receiving instructions via XR.

This article focuses on the testing process of XR-based technical instructions via the TIER model to explore how both designed and unintended affordances of the instructions are either noticed or not noticed, actualized (or ignored) by the users. The study represents a meta-experimental approach in which the testing, its method and data collection are also under the microscope. The study was undertaken in the tradition of user-centered design (UCD). According to Abras, Maloney-Krichmar and Preece (2014), in UCD “the end-users influence how a design takes shape.” Users are involved in UCD in some form or another, “typically during requirements gathering and usability testing” (ibid. p. 1). In the context of this research, this means focusing on the users’ actions and experiences when they start using XR-based technical instructions.

1.3 Technical Communication Professionals and User-Centered Design

Rising concern across fields has been in relation to human users and their roles in relation to the design process. The goal of UCD is to hold users – people who engage with and utilize digital designs – at the center of design processes in order to ensure relevance, usability, desire to use, and alliance with values to name some (see e.g., Dopp et al. 2019; Karat 1997).

In the tradition of UCD, a central facet of the work of technical communication professionals Over the past few decades, increasing emphasis has been placed on human users, and UCD has been one of the methodological approaches that technical communication has engaged in accordingly (Abras et al. 2014; LaRoche & Traynor 2010; Salvo 2001). Designing technical instructions for a new medium, such as XR, requires both theory and methods of alternate ways to present instructions within the environment⁴. Thus, as in any other domain of multimedia design, XR offers possibilities for text, images (3D models), videos, sound and increasingly more multisensory information (i.e., haptic sensations and perhaps even smell and taste in the future⁵).

In order to heighten fidelity, accuracy and even personalization of the product and experience within the individual interacting with the XR-based instructions, increasing amounts of data need to be collected from multiple sources (sensory

⁴ To exemplify the novelty of this area of scholarship, studies discussing the relationship between mode of information delivery or representation in XR and the user are concentrated in the area of learning and educational science (see e.g., Islam 2019).

⁵ Significant advances have occurred in the field of multisensory human-computer interaction (see e.g., Spence et al. 2016).

technology as well as user-fed information and user accounts). For this reason, technical instruction design is becoming ever more complex, as no longer is the human-instruction interaction a case of the individual engaging and utilizing the instructions, but it is necessary for the instructions and supporting technology to *use the user*. Thus, issues such as privacy and ethics are now also entering the discussion. As, although artificial intelligence (AI) is not the focus of this article, it must be acknowledged that the XR systems are increasingly powered by AI, which in turn, relies on large data for machine learning (ML)

The current research reports the results of two experiments. In the experiments, participants were presented with a simple set of instructions for building an abstract LEGO structure delivered via a VR head-mounted display. The tests sought to: 1) discern whether participants noticed the designed affordances; and 2) how they acted (real use) upon or reacted to those noticed affordances in the experiment. Thus, the main research question of the study is: in what ways can technology-based user behavior inform the design of XR-based technical instructions?

In order to understand the level of reliance on the details of the information delivered within the XR-based instructions, we pose a sub-question: To what extent do users rely on the details of the instructions – how much do individuals compensate for inadequacies by use of mental information contents (already learned and stored mentally bound information – i.e., memory, see e.g., Rousi, Saariluoma & Leikas 2010; Silvennoinen, Rousi, Jokinen & Perälä 2015)?

Thus, the XR-based instructions included a designed-in glitch: one LEGO block was replaced with a similar block of a different color. The glitch was included to investigate how the users acted when confronted by flawed technical instructions to see how the affordances of these instructions support cognitive fluency (Unkelbach 2006), supported by high level cognitive processing (top-down – from thought to perception) when perceiving information in the environment (Belke, Leder, Strobach & Carbon 2010).

This article is structured as follows: A literature review introduces research concerning XR-based technical instructions and their benefits. The results indicated that even very simple XR-based instructions could lead to various unexpected outcomes, highlighting the importance of an organized test process with the intended users of the instructions when starting to deliver them with a new medium.

2. Previous research

XR as an environment for technical instructions is still an emerging domain that is severely lacking in standardized empirical methods and theoretical models of the core factors concerning the design, experience and implications of this area of design. It is imperative to formulate a robust experiment design when studying testing XR-based solutions. This is due to the nature of XR itself. In addition to the AI and data-driven issues that emerge, communication modes and standards also pose challenges. For example, Verhulsdonck and Morie (2009, p. 8) raised awareness of a dilemma caused by the psycho-physiology of human beings when engaged in communication. In face-to-face contexts, many non-verbal elements and movements, such as eye gaze, are unintentional. In XR environments these movements may impact interaction, i.e., accidentally giving an eye-based command or selection, which thus affects the display. It may be difficult to design the instructions to account for unintentional user movements.

In the context of work, this requires special consideration. For example, from the point of view of how the hands of the user may or may not be available to make selections in the XR environment while performing different tasks in the real environment. Another example is the ability to warn users of critical work-related situations. As Burova et al. (2020) noted, previous professional experience influences the user's performance in specialized contexts. In their research, novice technicians required more interaction with warnings and needed situation-related warnings in order to catch their attention. Experienced technicians focused more on task performance and productivity, and considered extensive notifications irrelevant.

It is important to identify the characteristics that impact the user's safety, performance, and efficiency etc. In particular, it is crucial to pinpoint exactly what factors XR introduces to the context, in order to fully utilize the benefits of XR, and avoid the risks. However, target user groups, company culture, and the combination of equipment, technical devices, environments, tasks etc., form a unique composition of elements, or assemblage (see e.g., Delanda 2016). By this we acknowledge that use contexts are varied and dynamic, where every aspect within the context has some form of impact. There appears to be a lack of research concerning the actual test process and tools or models utilized. The need for a systematic experimental design has been recognized in previous research. Funk et al. (2015) studied AR-based assembly instructions and noted that variations in tasks and instruction modes rendered comparison difficult if not impossible between different use cases. Due to this dilemma, Funk et al. see the need for

theoretical models and standardized means for designing XR-based instructions for assembly tasks. Their answer to this need is the General Assembly Task Model.

That model proposed “a benchmark experiment design consisting of two cheap and easily reproducible assembly tasks” (Funk et al. 2015, p. 253). The tasks were an assembly task with Duplo bricks and a drilling task on a wooden board. The aim was to compare different approaches to instructions with a uniform benchmark. Funk et al.’s research indicates a problem in separate, task-oriented XR studies, and that is the difficulty in comparing results. For this reason, studies that examine the effectiveness and technological performance for instance, possess limitations, particularly if there are any inconsistencies between tasks, contexts, and purpose.

There are many usability studies of different types of technical instructions (see e.g., Alexander 2013; Sapienza 2004). A plethora of studies also focus on different types of XR employed in delivering various modes of instruction (see e.g., Tzimas et al. 2019; Doshi et al. 2017; Zauner et al. 2003; Hoedt et al. 2017). However, when it comes to usability tests for XR-based technical instructions, the amount of research decreases. The usability tests concerning XR-based solutions tend to focus on the hardware and software enabling the virtual or augmented experience (see e.g., An et al. 2020), rather than on the technical instructions themselves. There are some exceptions, however, like Fussell et al. (2019). Fussell and colleagues adopted a mixed methods approach to study the learnability, satisfaction and effectiveness of a VR-enabled tutorial for aviation training. Their results revealed that while engaging and usable, the design was cognitively loading particularly for novices. There was promise however, in that those who made errors and found the tutorials mentally taxing, still managed to correct their mistakes without external guidance.

As these studies indicate, organized and comparable experimental design with suitable models and tools for XR-based technical instructions are needed, to support in finding ideal solutions in regards to specific assemblages (cases). The following article reports an experiment in which TIER has been systematically applied to study usability and affordances within XR-based technical instructions. In particular, it focuses on how the affordance, or qualities of the VR, encouraged participants to progress with their tasks despite a designed-in glitch within the instructions.

3. Method

The research goal of this paper was to identify how the design of XR-based technical instructions could be informed by user behavior, especially from the

perspective of technological novelty. As previously noted, there are multiple variables to consider when both designing the technical instructions themselves, as well as when planning a UCD experiment. While it is difficult to account for all variables across diverse use contexts, it is important to utilize comprehensive models for even basic testing and experimentation of XR-based technical instructions. Users and use situations should always be at the center of iterative design and testing cycles in order to isolate the consistent factors that emerge across contexts. The aim of the study as to explore the effects when technical instruction users encounter and interact with novel XR-based instructions, while being expected to complete a task using those instructions.

3.1 Procedure

The first part of the study involved the formulation of XR-based technical instructions that would assist users (experiment participants) in assembling a LEGO construction. The rationale behind the choice of task hinges upon its simplicity – both ease in design of XR-based instruction, and simplicity that enables users to easily interpret and if necessary, ‘work around’ (modify instructions ad hoc if needed). This approach is in line with Funk et al. (2015) as well as Korn et al. (2013). Korn and colleagues’ work adopted a simplistic approach to ensure that the complexity of instructions would not be the confounding factor that hindered the effectiveness of the XR-enabled technical instructions. Their study was designed specifically with impaired production workers in mind, and utilized the Assistive Systems Experiment Designer (ASED) software to aid in the assembly process. The experimental set-up used in their examination comprised automatic logging of successfully completed assembly tasks.

Thus, the experiments in this current study examined the effectiveness of XR (or VR) as a medium for mediating technical instructions. The actual instructions played less of a role, despite the element of the built-in glitch. Focus was on to identify features when designing XR-enabled instructions, based on user responses to designed-in or accidental affordances. The researchers observed how participants acted upon or ignored functionalities offered. The instructions were developed especially for this experiment in order to avoid bias through familiarity (Casaló, Flavián & Guinalú 2008). The chosen form of XR was VR due to its simplicity and relatively cost and time efficient set-up, while still offering a fully immersive experience. The instructions were recorded with Insta360 One X camera. The end result was a one-minute long 360-video that showed the participants how to construct the LEGO shape, block-by-block. No speech nor

virtual elements were added. This is similar to the approach adopted by Funk and colleagues (2015) and Korn and colleagues (2013).

In this study the affordance model of technical instructions in extended reality (TIER) model was applied as an analytical framework and technique for conducting the experiments (see Figure 1). The TIER model has been piloted in (Rantakokko, submitted) in a similar test. Piloting results have shown that TIER is a suitable framework for this type of study, since it directs the focus toward the properties that should be delivered to users, and accounts for considerations of device and media types that are optimal for supporting effective delivery. Additionally, this is the first article in which the TIER model is systematically utilized in the testing phase of a design process for XR-based technical instructions. The focus is on the users, and in a normal design process of instructions, the feedback received from the testing phase would be instrumental for an iterative design process, indicating the types of changes the instructions may need before the next testing phase. This agile approach enables the detection of unintended affordances that could result in undesired outcomes.

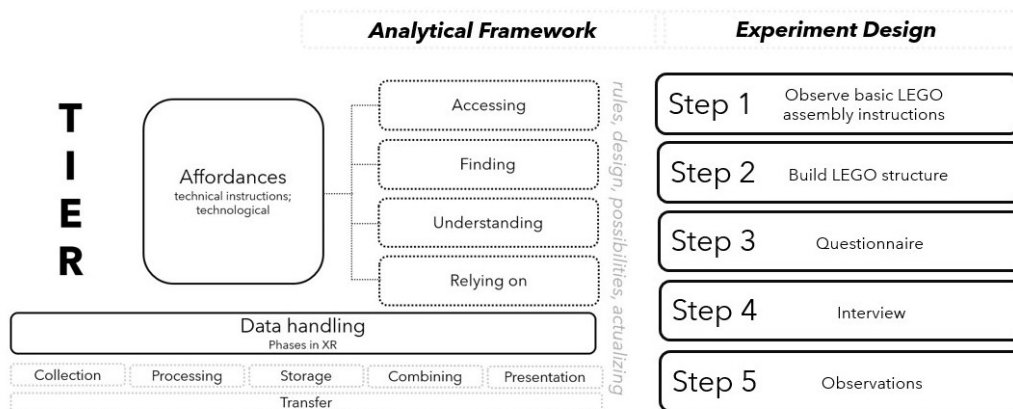


Fig. 1 TIER and its application as an analytical framework & experimental technique

The methodological approach is based on experimental research (see, i.e., Ross & Morrison 2004) aimed to identify whether the participants noticed the designed affordances, and how they acted upon or reacted to those affordances. The research consisted of two tests that were based on specific tasks that were mediated via the VR design. The data was collected via questionnaires, interviews, and observations of the experiment situations. The TIER model was used to both structure the experiment, as well as analyze the results. Application of TIER took place through dividing the properties of the XR-enabled instructions into two main domains: 1) affordances – what the technical instructions offer the user (how they

support the user's actions) and what the technology itself offers the user, the central possible functionalities that must be fulfilled for technical instructions (Rantakokko & Nuopponen 2019 - accessing, finding, understanding, and relying on); and 2) data handling – considering the types of data and methods implicated in operating this type of design combined with the phases of the data handling process in XR (collection, processing, storage, transfer, presentation, and combining data). The affordances are further evident via four levels in the TIER model: rules, design, possibilities, and actualizing. (Rantakokko 2022, p. 28 – 29)

The five experimental steps correspond with the affordance-based analytical framework that involves: accessing – gaining access to the instructions (equipment available and functions, WIFI available etc.); finding – orienting oneself between the instructions and VR environment, as well as the real world with physical components; understanding and in turn, actualizing the assembly process; and relying on – coming to depend on the instructions that are mediated through the technology rather than utilizing intuition and memorized actions from previous experience (Rantakokko 2022). The understanding and actualizing components were operationalized in Step 2. Steps 3 and 4 sought subjective reporting from participants, and Step 5 was determinant on research observations.

3.2 Research design

The experiment involved the construction of a LEGO structure, as shown in Figure 2. The task instructions were delivered via 360-degree VR-based video in which the assembly procedure was shown step-by-step. No linguistically-based instructions (i.e., written or verbal) were used to ensure fidelity between image and real world. The researcher introduced the task to the participants. They were then requested to independently complete the task without interacting with the researcher, and then to complete a questionnaire. The participants were interviewed after completing the questionnaire.



Fig. 2 LEGO construction from the instruction video

The instruction video showed 20 LEGO blocks. Five of these blocks were correct, and were used in the demonstration of how to assemble the construction in the right order. Before commencement, the blocks were arranged on a black surface. Again, black was chosen as the surface color due to its simple shade and high contrast. The initial arrangement of pieces can be seen in Figure 3.

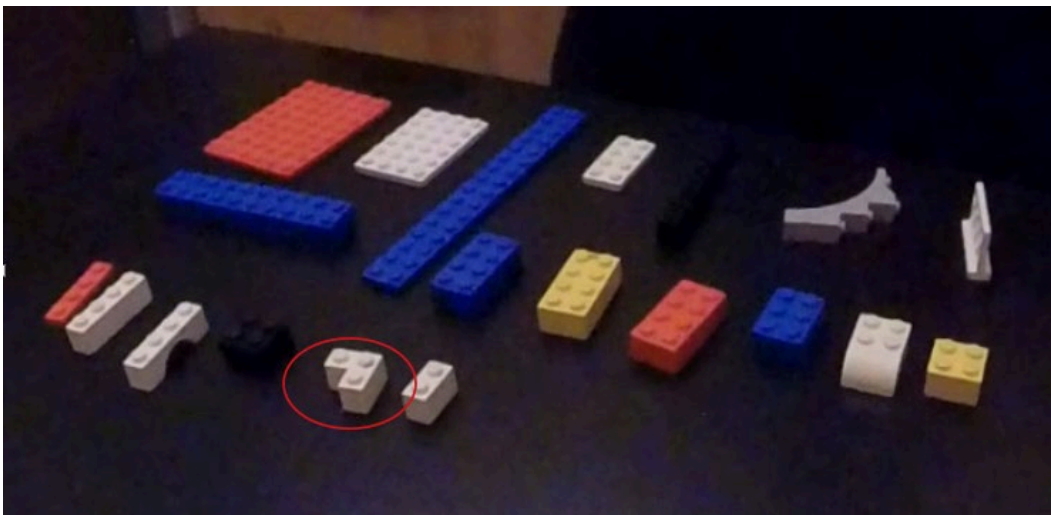


Fig. 3 Arrangement of LEGO pieces in the 360-degree video instructions

The participants were not told that the experiment would include a designed-in glitch. The piece circled in Figure 4 was replaced with another piece among the LEGO pieces to be utilized for the actual experiment. This was to investigate how much the participants relied on the instructions themselves (as seen relation to the TIER affordances), and how much the possibilities of the technology allowed participants to improvise (combining constructional memory with initiative in light of available building blocks). Otherwise, the instructions were consistent with the real-world components. The purpose of this glitch was to observe how the users would act in a situation where the task was simple but flawed. The situation was intended to reflect work situations in which real world conditions do not match the details of the technical instructions. The idea was to observe the level of fixation with detail between the technical instructions and the participant's real-world resources and actions. On this note, Table 1 presents the participants, materials, and instruments involved in the experiments.

Table 1 Experimental variables in Test 1 and Test 2 – participants, materials, instruments

	Test 1	Test 2
Participants:		
Little or no experience with XR		
Number	4	4
Gender	3 male, 1 female	4 female
Age	27–72	23–39
Recruitment	Convenience sampling	Convenience sampling
Material:		
Guidance for test procedure	Verbal instructions, printed procedural instructions	Verbal instructions, printed procedural instructions
Equipment	VR Shinecon + Fairphone 3	Oculus Quest VR+ Fairphone 3
Task instructions	VR-based video	VR-based video
Environment:	Home environment	Laboratory
Instruments for data gathering:		
	Questionnaire, interview, observation	Questionnaire, interview, observation

The main differences between these two experiments was the environment, and the equipment used. In test 1, the environment was cozy, home-like room, and the equipment a low-quality budget VR glasses. This was to build an amateurish and less formal impression, which may influence the participants' reliance on the instructions, but also make them more relaxed. The second experiment was

conducted in a lab environment with standard-quality VR glasses. This could give more professional impression of the experiment.

3.2.1 Participants

The participants were recruited via convenience sampling. The research design received approval from the university's ethics committee. Overall, there were eight participants in the tests, ages 23 –72, of which three were male and five were female. All of the participants possessed either no or little experience with XR technology. Those with a little experience had used the technology once or twice previously. The number of participants was limited because the research did not aim to evaluate designed instructions themselves. Rather, the goal here was to produce information on how the user's actions and reactions could be used to inform the design of XR-based technical instructions. That is, through focusing on aspects related to the TIER model in terms of accessing, finding, understanding and relying on, it was hoped that fruitful information would be derived on what properties enhanced which factor and why.

Convenience sampling was chosen due to the challenges that the COVID-19 pandemic conditions placed on recruitment and participation in empirical research. The study participants represented diverse backgrounds and ages. While small, the sample was intended to be pre-emptive of the variation among users in real work environments. A generic approach was taken to the type of instructions and use context applied in the experiment. Yet, in future research when specific technical instruction design is developed and tested, it will be important to recruit professionals and users from the specific areas in question.

3.2.2 Material and equipment

The material consisted of the experiment guidance, equipment, and instructions to complete the task. The guidance for the test procedure was both verbal and supplied in printed form. The instructions included practical guidance for the test, its purpose, and how the collected data would be used. Furthermore, the participants were informed that they are allowed to withdraw from the test at any time if they chose to do so. They were also informed that the test was not focused on them, but the instructions and how they supported the construction process. Therefore, if they would not succeed to complete the task according to the instructions, this would indicate usability issues regarding the instructions.

The equipment mediating the technical instructions in Test 1 comprised the VR Shinecon virtual glasses (see Figure 4). These are low-quality budget glasses

designed to be used with a smartphone placed inside. The smartphone used was a Fairphone 3. In Test 2, the instructions were mediated via Oculus Quest VR glasses. These are standard-quality VR glasses providing a wireless VR experience that include two controls. The quality of the Oculus Quest is significantly better than the VR Shinecon. The choice of equipment was two-fold. Firstly, these devices were available and used within the context of the research facilities, as well as during specific points of the pandemic. Secondly, the devices offered insight into the cross-platform effectiveness of the technical instructions in VR. In particular, it is noted that internationally the demographics of potential users will vary greatly, meaning that while one user group will have access to the likes of Oculus Quest, another group will be limited to devices similar to VR Shinecon. Therefore, the researchers were interested in understanding how the instructions operate in general across devices.

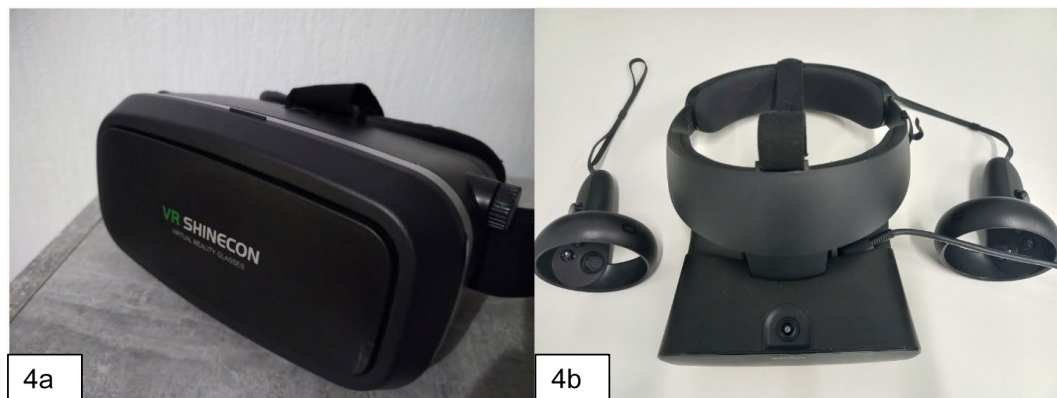


Fig. 4 VR Shinecon glasses (4a); Oculus Quest (4b)

3.2.3 Data collection

A mixed method approach was adopted in this study. The data collection was conducted with questionnaires, observation, and interviews. Thus, data includes quantitative and qualitative data. While the participants were engaging with the task, the situation was video recorded and subsequently underwent observational analysis. After the participants had finished the task, they were asked to complete the questionnaire. The questions and the answers of the questionnaire are introduced and analyzed in Results section, and listed in Tables 3 - 6. Mainly, the questionnaire included questions with answers on a Likert scale. This was supplemented with open questions.

Upon completing the questionnaire each participant was interviewed. The interviews were exploratory and tailored based on what happened during the

experiment as well as the answers they had given in the questionnaire. The participants were also encouraged to discuss anything they felt important.

3.3 Procedure

The participants were instructed both verbally and via a printed information sheet. The technical instructions in Test 1 played in a continuous loop. The participants were allowed to watch them as many times as they felt necessary before and during the building task. In Test 2, it was possible to pause and re-start the instructions at any time. In Test 1, the instructions were watched from a seated position next to the table with the LEGO blocks. In Test 2, the instructions were viewed in a designated observation area while standing. Outside the observation area, the instructions became translucent. In Test 1, the environment was an informal, simple household room. Test 2 was conducted in a lab environment. The central elements can be seen in Table 2.

Table 2 Central elements of the test procedure

Test 1	Test 2
VR-based instructions for the building task:	
Shown via continuous loop	Ability to pause and resume viewing
Test environment:	
Informal environment	Laboratory environment
Variables (Devices):	
VR Shinecon + Fairphone	Oculus Quest
Manipulation: Designed-in glitch	
Observing: Recording of the test situation + live observations	
Questionnaires: Pre-interview questionnaire (Questions represented in Tables 3-6 in Results section)	
Interviews: Based on observations of the test situations and answers to questionnaires	

The researcher undertook live observations in addition to recording the sessions via video (on a smartphone device). These videos were later transcribed. Participants were not to interact with the researcher while performing tasks. Despite this instruction, all participants did speak to the researcher. It was decided during the experiments that the tasks would still be completed despite this issue, as the information offered freely by participants during the tasks served as thinking aloud data. The post-questionnaire and post-experiment interview focused on what was observed during the experiment, as well as the answers to the

questionnaire. One standard question that was asked to all participants regarded whether or not they had noticed the designed-in glitch.

3.4 Data analysis

The interviews and experiments were video recorded and later transcribed, with every action timestamped. The transcriptions were read through several times, and only relevant observations were retained in the data. Exclusion criteria included unrelated actions such as scratching one's nose. The chosen data was then combined in matrix tables that separately represented the data from each experiment and each test group. The data of both experiments was combined to create overall findings tables.

The tables were then analyzed in light of the TIER model (Rantakokko 2022). The TIER model was utilized according to its levels of affordances that represent different phases of the design process. Therefore, as this research focuses on the testing phase, relevant parts of the TIER model were chosen (see Figure 5).

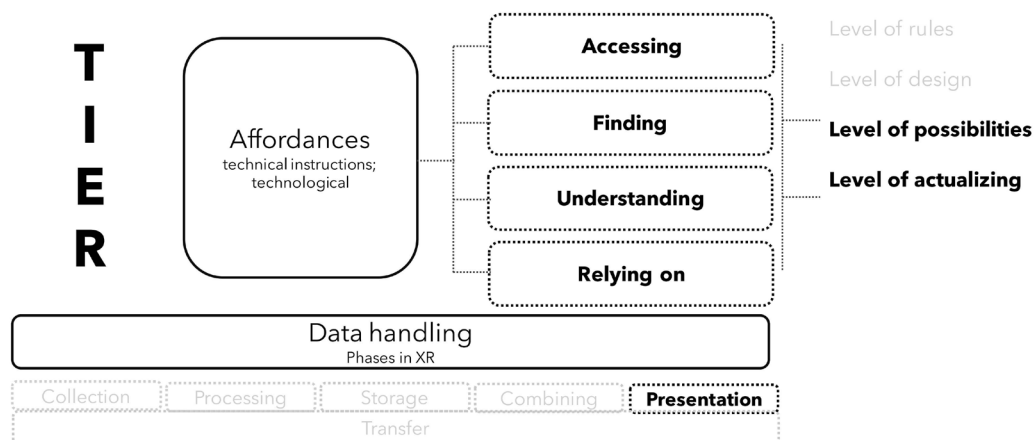


Fig. 5 Selected facets of TIER model utilized in the study

In this research, all the affordances of technical instructions were relevant. Due to the fact that the research focused on the users' actions and how the designed or unintended affordances actualized while users were engaging in the tasks, the focus was on the levels of possibilities and actualizing. The users evaluated the XR-based instructions and used them to complete the task, therefore, focus was on the presentation phase of XR data handling.

In order to operationalize the TIER model for the analysis, all observational notes were inserted into the matrix tables. The tables are presented in the results section. These notes were then categorized according to affordances and the levels that the notes were related to. For example, some notes focused on the affordance of accessing, particularly since the XR technology used in this study was VR. This meant that, participants could only see the instructions while wearing the head-mounted display (HMD). Yet, similarly, participants needed to remove the HMD to undertake the tasks in the real-world. If the user could not use the HMD or the technical instructions due to how they were mediated via the devices, the affordance of accessing would not be actualized.

The analysis considered the affordances noticed by the participants. The approach permitted an organized comparison of the results and what they indicated regarding the affordances featured in the tests.

In a design process of actual XR-based instructions, the TIER model could be used as follows. First, relevant laws, regulations and guidance should be taken into consideration, as well as other desired features of the XR-based technical instructions to be designed. These features would be placed into the matrix tables of the TIER model. When the first version of the instructions is ready to be tested, the results of each feature would be easy to evaluate, as it is readily seen from the table. If the designed affordances are noticed by users (level of possibilities) and if users act upon them (level of actualizing), these are entered into the TIER table. In the experiment design of the current research, the designed-in affordances pertained to the technical instructions and how they could be accessed, found and understood, in order to construct a LEGO form. The instructions included a designed-in glitch that rendered it impossible to build an identical construction. This in turned tested the error handling and relying on factors of interaction between users and XR-enabled technical instructions.

4. Results

The research question of this paper was: In what ways can technology-based user behavior inform the design of XR-based technical instructions? To answer this question, data was gathered from two experiments focused on testing XR-based technical instructions. In these experiments users were studied in terms of how they acted upon the affordances they noticed during test situations. Attention was also placed on how this information could be applied to the design of XR-based technical instructions.

The experiments mainly focused on the level of actualizing. Participants tried to complete the task with the guidance of XR-based technical instructions and evaluated the instructions by following the guidance. Although only a few variables were designed into the tests, and the instructions were made as simple as possible, anomalies were still observed during the test processes. Anomalies are characterized based on if they were noticed (level of possibilities) by the participants, and what, if any, actions followed (level of actualizing). Combined notes from the tests and the observed anomalies are introduced in Tables 3–6. First, Table 3, presents the combined key notes concerning the affordance of *accessing*.

4.1 The affordance of accessing

Table 3 Key notes from the experiments related to the affordance of accessing

Accessing	
Questionnaire responses	
Test 1	Test 2
Q: How did you experience using the VR glasses?	
Extremely easy (1), relatively easy (2), neither easy nor difficult (1)	Relatively easy (4)
Q: Did you experience problems using the VR glasses during the test?	
Sharpness (2), loose glasses (1), no problems (1)	Wi-Fi problem (1), problems adapting to VR glasses (1), no problems (2)
Q: Did problems occur during the test that you would have needed assistance with?	
No problems (2), sharpness (1), uncertainty around block replacement (1)	No problems (3), Wi-Fi (1)
Anomalies observed	
Level of possibilities	Level of actualizing
<i>Difficulties in fitting the VR glasses</i>	
Noticed	Succeeding to fit, or holding them with one hand
<i>Difficulties to see</i>	
Noticed	Finishes with insecurities
<i>Glasses opened at one point while put on the table</i>	
Unclear if noticed	Was not possible to continue before fixing
<i>Smartphone heated up badly during the tests</i>	
Noticed by the observant	Did not complicate the tests, possible problem in long-time work situations
<i>Online connection failed</i>	

Noticed

Was not possible to start before connection restored

Equipment-related notes are marked under the affordance of accessing. This is because XR-based technical instructions cannot be accessed without the equipment. Using XR (in this case, VR) glasses was evaluated positively in both tests despite the differences in devices. In Test 1, the answers varied from *neither easy nor difficult* to *extremely easy*, while in Test 2, everyone answered *relatively easy*. However, when participants were asked specifically about possible problems they may have experienced during the test with XR equipment, they listed several issues.

The questionnaire included a question about the problems faced during the test concerning XR equipment in general, and another on problems that participants would have needed help with during the test. Despite being instructed not to interact with the researcher, all participants did either speak or ask for assistance during the procedure. Thus, the second question was automatically answered. Yes, there were aspects that participants needed help with. In order to have discouraged interaction, the researcher should have been located further away from the test area. This was however, not possible. The decision to allow communication during the experiments enabled continuity of the tests that otherwise may have been disrupted. More tests with users working on their own would be required if developing actual XR-based technical instructions in order to see how the users would operate in situations of independent work.

Problems reported by participants in Test 1 included poor-fitting glasses (HMD) and poor sharpness. Assistance would have been needed with sharpness issues. Uncertainty of where in the construction certain pieces should be placed was mentioned as a problem that would have benefited with assistance. Problems reported in Test 2 included Wi-Fi problems, taking time to realize how the system works (i.e., warm-up tests), and adjusting to the conditions of the HMD in order to identify objects clearly. One participant required assistance with the Wi-Fi problem. Half of the participants in Test 1 and three out of four in Test 2 mentioned that there was no need for assistance. There were other issues that would have needed assistance. Therefore, it would be important to first assist the users and later on instruct with the issues that may occur more often. More tests would show which issues keep repeating and which ones seldom occur.

The Wi-Fi failure is worth highlighting. Concerning this experiment, it would have been possible to have only watched the instructions via regular video. However,

leaving the experiment at the mere watching of a video would not have probed the reality of interacting with technical instructions in VR. In the work environment, failure of the Wi-Fi connection could mean a disruption to the work process if there is no back-up (i.e., offline mode and functionalities). If the work task is a response to a critical situation at a distant location, Wi-Fi failure can be catastrophic. Therefore, offline-mode and hard copy backups should be required to guarantee access to crucial instructions at all times.

Interestingly, the participants reported that they found using the XR equipment relatively easy, even though most of them faced at least some problems during the experiment, mostly with the equipment. In Test 1, trying to adjust sharpness was problematic and not usually resolved fully. In addition, fitting the headset was challenging. The fitting problems were usually resolved by adjusting the glasses, but sometimes the participants had to hold the glasses with one hand. In Test 2, the participants had more control and could start and pause the instructions via the equipment's user interface. However, the basic usage of the equipment was relatively convenient and effective, and most people got the headwear to fit correctly. Nobody had issues with understanding the basic functions. As mentioned before, observing the testing of different equipment was useful as participants did not actively mention the problems themselves. With a new technology, it may not be easy to notice problems until having more experience. For this reason, giving participants the opportunity to test different devices may aid in deepening understanding of what device is more effective for what purpose. This adds an extra yet necessary layer to testing XR-based technical instructions, as the experience does not purely hinge upon one technical factor, rather several (see studies such as, Bowman et al. 2002; Kaewkannate & Kim 2016).

While there may be situations in which professionals cannot influence the device used by their employer, there may be opportunities in some cases to participate in the organization's purchasing decisions. This in itself is an important part of user experience, employee engagement, organizational citizenship, and sustainability adoption of information technology (see, Nikas & Poulymenakou 2008). Thus, via experience professionals strengthen knowledge of optimal devices for particular technical instruction modes and purposes.

Anomalies not noticed or mentioned by the participants, were the glasses opening at one point during Test 1 with one participant, and the smart phone inside the headset heating substantially. While the glasses opened, they did not break, so the test could continue after the observer closed them. However, if this happened in a critical work situation the results could be detrimental. It remains uncertain as to whether the participant noticed the situation, because it seemed that the

participant's focus was on the task at hand, rather than trying to fix the problem. The heating of the smart phone seemed to not be noticed by participants. This was due to the fact that they did not have to touch the smart phone inside the glasses, and it did not affect the tests. However, in general, the overheating issue would probably prohibit use of that technological solution daily for long periods. In the design process of real XR-based technical instructions, these would be some of the issues that would need to be considered. This has often been noted in research focusing on the design of healthcare systems (Bitkina, Kim & Park 2020).

4.2 The affordance of finding

Notes on the affordance of *finding* are introduced in Table 4. Completion times mostly relate to how well the participants could find the right information. The instructions were in 360-degree video form that played on continuous loop in Test 1. Here, participants could not pause it at any time. In Test 2, when the participants needed to re-visit information, they either located the spot in the video where it was shown by pausing and scrolling back, or let the video roll until the right spot was reached again. These results were not compared with other media. It would be surprising however, if this solution would make completion times shorter than other types of instructions. If the participants were fast, the instruction video was still one minute long in both experiments, and therefore all the participants had to use at least this amount of time with the instructions before or during the task. If they were insecure, they checked the instructions multiple times. Had the participants used instructions delivered via any other medium (i.e., AR, paper instructions or even television – no requiring full eye coverage), they would have had the option to start the task while watching the instructions. Three participants developed a workaround (a way of continuing work flow despite usability and technical flaws, see Ejneffjäll & Ågerfalk 2019) for this medium as well.

Table 4 Observation findings from Tests 1 and 2 – affordance of finding

Finding							
Questionnaire responses							
Test 1				Test 2			
<i>Task completion time (from start to completion)</i>							
0:24	2:38	7:22	4:27	2:28	2:51	1:58	5:49
<i>First checks</i>							
1	8-9	1	1	1	1	1	1
<i>Re-checks</i>							
1	1	Ongoing	Ongoing	Ongoing	1	2	3

Q: How many times did you need to watch the instructions?	
2, 3, 4, 3	5, 2, 3 times + an extra time to make sure everything is correct, 1 time completely plus two separate sections
Anomalies observed	
Level of possibilities	Level of actualizing
VR does not allow users to see actual reality	
Noticed	Having to put glasses on and off during the task
Three-page form misunderstood as a one-page form	
Not noticed	Participants were informed about the page account, so they filled in all the pages
Forgetting (or fear of forgetting) instructions read or seen	
Noticed / not noticed	Re-checks for confirmation
Slowness of watching the VR video (no rewind)	
Noticed	Completed at a slower pace
Requires getting used to initially (Participant 1.2)	
Noticed	Insecurities in the beginning
Direction of the video had a glitch and kept reversing (Test 2)	
Noticed	Necessity to continuously turn
Having to move while wearing the glasses can cause dangerous situations	
Not noticed	Kept moving, did not react to warning
Focusing only on one direction	
Not noticed	If the relevant information was situated in more than one spot in the video, it might not be noticed

Anomalies concerning the affordance of finding are detailed here. VR is completely immersive and removes users from ocular (sight) contact with the real world. This is already a known property regarding the system. However, in the context of technical instructions this poses an extra challenge to successfully using the system to carry out actions related to the instructions. In a task that requires assembling a physical structure, complete immersion of VR is an issue unless the use purpose is for remote assembling, whereby a robot or other augmented technology undertakes the physical actions. Ordinarily, removal from the immediate physical environment and negotiation between the two spaces (virtual and real) increases cognitive workload (Andersen et al. 2016; Kosch et al. 2023). This was exacerbated

since the participants were either forced to remember the instructions, or to re-check them.

Fear of forgetting created further delays. Since the instructions were based on the video structure, watching the instructions was a slow process, especially in Test 1, where participants could not control the video. One participant in Test 1 wished for a rewind function. In Test 2, participants were able to control the video with pause and replay etc. Even though this issue was expected, this result highlights the importance of testing.

For one participant in Test 2, the VR system had a glitch and the direction of the video kept reversing 180 degrees. Therefore, the participant needed to continuously move around in order to be able to watch the instructions. Sudden movements posed a risk because the participant nearly bumped into objects in the real-world whilst not being able to see the objects. Furthermore, the participant did not hear when warned not to move so much. Physical safety during the use of equipment is crucial at all times, as witnessed in similar XR cases such as Pokémon GO (Serino et al. 2016). The environment needs to be designed so that there are no immediate physical dangers. In work environments, VR-based solutions that completely block the view of physical objects should be positioned in controlled spaces.

Only a few of the problems were mentioned by the participants. Of these problems, visual difficulties were the most mentioned in Test 1. The issue was caused by the poor quality of the VR HMD used. This HMD did not accommodate for participant eye glasses. In this category, there was the factor of it sometimes being difficult to see from the instruction video where exactly the blocks were situated in the structure. These visibility issues did not cause any of the participants to exit the task. Instead, they created workarounds by guessing, reasoning, and trying to mathematically estimate the locations and appropriate pieces to be used. Difficulties to see also resulted in longer task times and some degree of frustration.

It was noted that none of the participants using VR glasses took time to look around the virtual environment. They all focused directly on the target area. Had there been important elements in more than one location, participants may not have noticed them. If total environments are used in the instructions, it could be relevant to inform the users that they should look around. Furthermore, other multisensory elements such as sound and vibration etc., could be used to enhance the visual elements and indicate locations of information.

4.3 The affordance of understanding

The affordance of *understanding* was reported to be *very easy* by six of the participants. Two reported understanding to be *relatively easy*. Regarding possible flaws, seven of eight participants found the instructions to be functional. However, the instructions were indeed not functional because the designed-in glitch made it impossible to build the exact same structure. Despite this, each participant answered that they successfully completed the task with the help of the instructions. Most of the participants built almost the same form, just replacing the irregular piece with a similar shaped piece of a different color. The key notes regarding affordance of understanding are presented in Table 5.

Table 5 Observations from Tests 1 and 2 related to the affordance of understanding

Understanding	
Questionnaire responses	
Test 1	Test 2
Q: <i>Did you find the instructions understandable?</i>	
Very easy to understand (2), relatively easy to understand (2)	Very easy to understand (4)
Q: <i>In general, did you find the instructions functional, or were there flaws?</i>	
Functional (4) with one comment about rewinding functionality	Functional (3), Flawed with a mention of the designed-in glitch (1)
Q: <i>Did you succeed in building the LEGO construction by following the instructions?</i>	
Yes (4)	Yes (4)
Anomalies observed	
Level of possibilities	Level of actualizing
The designed-in glitch	
Noticed by some	Finished with the wrong colored block
Voice narration would have been beneficial	
Noticed	Finished without voice narration
Characters in the video too big (Test 2)	
Noticed	Having to look up and down

Anomalies concerning the affordance of understanding consisted of the designed-in glitch and unintended scaling issues of the instructions and real-world

conditions. One participant mentioned that audible instructions would have been beneficial.

Participants tended not to mention the glitch. When asked later, most of them had noticed the glitch but did not find it relevant or worth mentioning. This finding might signal an issue in real work situations. It does however, at least indicate that sometimes people reason that minor flaws are unimportant and can be worked around (see e.g., Fuller & Arnold 2019). Thus, when flaws could be ignored by slight modification, participants did not explicitly verbally articulate the flaws. Only one participant mentioned the glitch and was disturbed by it, but even that participant finished the task. Following the work flow during the test periods would be helpful. If it cannot be trusted that the test participants either notice or voice flaws, then observations are instrumental in detecting subconscious behavior (Awan, Esteve & van Witteloostuijn 2020). Following eye gaze paths could indicate whether or not they have noticed flaws they assume are not important.

All the participants justified how the task was possible to finish regardless of the glitch. Participant 1 from Test 1 ignored the glitch because, *“it was LEGO, and the color didn’t matter.”* Participant 4 of Test 1 explained:

“The shape was correct. In such a situation, you look at the blocks on the table and when the video ends here, then you know that the wrongly colored block can be used. But if the video continues, there is no way to know if that block will be needed later. So, then you can say that now you cannot continue since there is not a block of that color and shape.”

In the opinion of this participant, *“the general idea is that if you do something, you use it if it fits.”* None of the participants left the task unfinished on account of the glitch.

In Test 2, the instruction video featured an unintended surprise that was not present in Test 1. Using Oculus Quest headsets made the images and contents of the virtual environment extremely large, which forced participants to continuously look up and down. This can be likened to watching a giant building with huge LEGO pieces. The size difference between the pieces in the VR instructions and the real-world pieces on the table was disturbing for some of the participants. Elements such as voice instructions would have been beneficial, especially for the participants who struggled to see well. Choosing the right equipment and adjusting the design of the instructions for that equipment is pertinent. Changing the equipment at a later stage may result in distortion of visual outputs.

4.4 The affordance of relying on

With the affordance of *relying on*, the differences in Tests 1 and 2 were remarkable. In Test 1, all four participants would have chosen VR-based instructions over paper instructions. However, in Test 2, only one participant preferred VR-based instructions over a paper version (see Table 5). In a more complex task, two of the participants in Test 1 would have preferred VR-based instructions over other forms. In Test 2, all participants would have preferred other forms. The reliance experienced was high in general, especially in Test 1, where three out of four participants found the XR-based instructions to be *very reliable* and one described them as *relatively reliable*. In Test 2, one informant found the instructions to be *very reliable*, and three reported them to be *relatively reliable*. Observations are reported in Table 6.

Table 6 Observations of Tests 1 and 2 related to the affordance of relying on

Relying on	
Questionnaire responses	
Test 1	Test 2
Q: <i>Would you rather use paper instructions (possibly with pictures) or VR instructions like these?</i>	
Rather VR instructions (4)	Rather paper (3), rather VR (1)
Q: <i>Would you rather use Youtube instruction videos, or VR instructions like these?</i>	
Rather VR (3), Blank (1)	Rather video (3), rather VR (1)
Q: <i>In the case of a more complex task, e.g., LEGO construction of 50 pieces, what type of instructions would you rather use?</i>	
VR (2) (1 stated that it would be better to see through the HMD, thus preferring AR even though not naming it), Video (1), Video/VR (1)	Paper (2), video (1), paper / video (1)
Q: <i>Did you find the instructions reliable? (referring to instructional content and VR HMD)</i>	
Very (3), Relatively (1)	Very (1), Relatively (3)
Anomalies observed	
Level of possibilities	Level of actualizing
Insecurity about instructions and how to act	
Noticed	Sometimes hesitating to ask when needing help, making decisions to act or attempting to respond in a way they feel the researcher is wanting.
Not relying on the technology (Participant 4)	
Noticed	Based on previous experiences, reluctance to engage in regular use.

In the experiments, the answers concerning the reliance on XR technology are not completely related to participants' preconceptions. Instead, the experiences during the experiments may have contributed either positively or negatively to how reliable participants believed XR equipment in general was as a medium for technical instructions.

Anomalies that arose regarding the affordance of relying on were insecurity about the instructions and how to act, and not relying on the technology in general. The insecurities seemed to slow down the participants' performance, sometimes remarkably, while they gathered the courage to ask for further information from the researcher. One participant had negative experiences in the past that related to the causing of headaches and eye fatigue. This influenced the participant's opinion that the technology was not reliable. The participant in question was willing to undertake the test, but expressed reluctance to use XR-enabled instructions in regular bases, such as in work or studies. This was despite the fact that the symptoms did not reoccur during this study. Allowing the participants to rehearse usage of the system would have reduced insecurities⁶. When new technological solutions become familiar, it is easier to give feedback and see which features would be important to improve, and which features are well-functioning as they are⁷. Therefore, the testing phase should include longer use periods of the equipment, and several occasions to use. Feedback should be iteratively collected.

If this would be a design process of actual XR-based technical instructions, there would be the need to engage in another iteration sprint. After possible improvements, the next round of tests would be conducted, reported, and compared to see if there is improvement. This article reports one way to complete the process via the assistance of the TIER model. It shows how the actions of the users in response to new technology informs the design of XR-based technical instructions via feedback.

5. Conclusions

This research aimed to identify how the design of XR-based technical instructions is informed when the actions of users in relation to new technology are considered. The answer was sought via two empirical tests, and the analysis of the results was structured according to the TIER model. The tests were conducted using simple VR-based instructions. The participants' task was to complete the construction of

⁶ This is commonly used in driving simulation studies (see e.g., Godley, Triggs & Fildes 2002).

⁷ This has been noted in relation to concept familiarity for instance (see e.g., Grooms, Sampson & Enderle 2018).

a LEGO structure by following the instructions. The data was gathered via questionnaires, interviews, and observations. The TIER model has been designed to support and analyze the organized, step-by-step design process of XR-based technical instructions. It begins with laws and regulations, continued by designing the desired affordances, and moves towards testing and re-designing or re-iterating the technical instruction design.

Since XR changes the design process and the use situations of technical instructions that are delivered via the medium, it is important to conduct a thorough and iterative test process of the instructions, while involving users in the process. One way to do this is by testing users' interaction with the system (Abrams et al. 2014, p. 9), as is done in this research. The focus of the current paper is on an organized and comparable test process of XR-based technical instructions.

The test results indicated that even when using simple XR-based instructions, several unexpected events can occur. Most of the problems or inconveniences were found via observations and discussions based on the observations. Only a few problems were mentioned in the questionnaire responses. Furthermore, the participants often did not mention the flaws they noticed, if they were not directly asked about the specific flaw in question. In these tests, a glitch was deliberately designed into the instructions. The glitch entailed that one LEGO piece present in the instructions was replaced with a similar piece of a different color. Most of the participants noticed the glitch, but did not mention it. They simply replaced the wrongly colored piece with another of another color. All the participants reported they had completed the task.

These findings highlight the importance of observation rather than basing the test process merely on the users' evaluations (see, e.g., Gram 2010). This is because the evaluations can be flawed in several ways, such as not noticing the problems or deciding that the problems noticed are not relevant. There may be several reasons for participants not reporting the problems that occurred during the tests, or the designed-in glitch even if they noticed it. One possible reason seemed to be a willingness to disregard issues to be polite to the researcher. That could be an issue in work environments. Participants also seemed to be willing to do as they perceived that they were supposed to. Even though their capabilities were not the subject of the research, people often tend to try to succeed in a test situation (see, e.g., Nederhof 1985; Ming et al. 2021). The inclination could be socially accepted by the researcher, is classified as "the tendency of some respondents to report an answer in a way they deem to be more socially acceptable than would be their "true" answer. They do this to project a favorable image of themselves and to avoid receiving negative evaluations." (Callegaro 2008, p. 826)

Reluctance to mention or focus on problems may originate also from the new experience in general. Norman (2002, p. 41) noted:

Any pleasure derivable from the appearance or functioning of the tool increases positive affect, broadening the creativity and increasing the tolerance for minor difficulties and blockages. Minor problems in the design are overlooked. The changes in processing style released by positive affect aid in creative problem solving that is apt to overcome both difficulties encountered in the activity and those created by the interface design. In other words, when we feel good, we overlook design faults.

Because all the participants were rather unexperienced with XR, there may have been a tendency to overlook minor problems while enjoying the new experience. This needs to be taken into consideration in real tests in the work environment as well. Further testing is needed for longer periods to ensure that this bias does not affect evaluations. This phenomenon is also related to the halo effect, in which emotions and attitudes towards phenomena may bias judgements (Minge & Thüring 2018, p. 23).

There are some limitations to this research. First, the instructions were perhaps too simple, and did not include interactive elements. Therefore, it is debatable whether they can be counted as XR-based instructions. This is because the aim was to keep them as simple as possible and focus on the affordances that the users noticed in order to illustrate how the TIER model functions within user testing of XR-based technical instructions. Having more variables in the instructions might have compromised the understanding of the results of this particular research design.

Second, pondering over the reliability of the experiment design in light of the research question there may be debate. While only using LEGO pieces in this research, many people have prior experience in LEGO construction. This may have influenced their attitudes towards color accuracy. Therefore, it could be understood that using LEGO is possibly not so effective in the study of technical instructions. However, this solution has also been used before (see e.g., Funk et al. 2015; Korn et al. 2013).

Third, there was no clear inclusion or exclusion criteria of participants. Thus, the characteristics of participants were not decided or classified prior to the experiments. This led to factor-related uncertainty regarding the participants within the groups of Test 1 and 2. For instance, numerous variables may have influenced the participants' experience of the designs. These include, educational

background, experience with technology, age profiles, test environments, and even the types of equipment utilized.

Fourth, control methods of usability testing were not used in this research in an organized matter. This is because in the current research, the purpose was not to develop functional technical instructions, the design process did not continue with an iterative process as it normally would. It was already anticipated however, that feedback would be given by participants regarding its unsuitability for the use context in question. This pertains to the fact that users of assembly instructions often interact with the real physical environment at the same time as following instructions. Thus, in an actual use environment, AR would be the ideal XR method. It was assumed in this study that if participants would not verbally mention this aspect, then potentially other crucial information would be missing from their interviews.

Fifth, in this research it was not possible to conduct a comparison of different types of XR-based solutions. As Fast-Berglund et al. (2018, p. 37) state, different types of XR are effective in different manufacturing phases and various solutions even with the same type of XR may lead to very different outcomes. Therefore, a preliminary comparison before choosing a certain type of XR would be crucial to conduct. Conducting preliminary comparisons could place strain on resources (time and financial).

Therefore, future research should concentrate on investigating alternative means and methods for testing and comparing XR-based technical solutions systematically. Moreover, it would be important to test the TIER model in an actual design process of XR-based instructions. Other research directions may include the comparison of XR-based technical instructions and their usability via methods that enable the analysis and comparison, such as seen in the TIER model. This would offer more information in terms of what solutions may be most relevant and successful for intended purposes. This research is an attempt to organize the test process in a way that would be useful in actual design processes of real XR-based technical instructions.

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