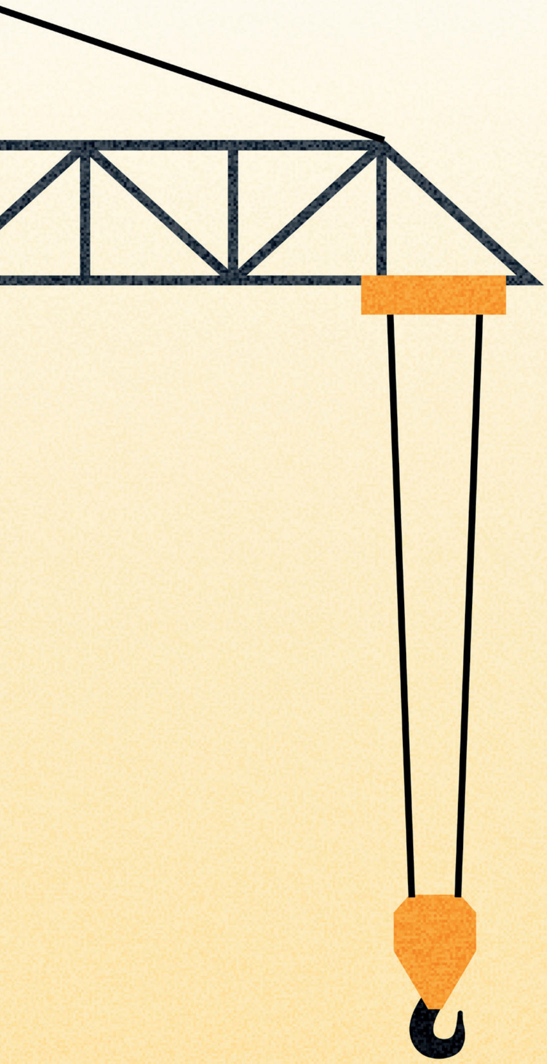
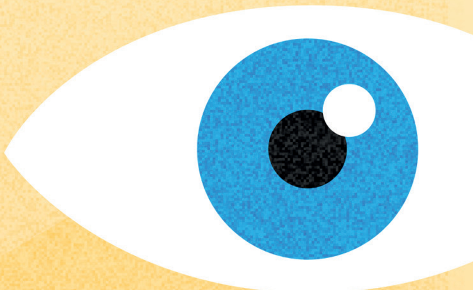




Eleonora Nava

Exploring visualisation techniques in VR to enhance memory and engagement for the purpose of introducing professions to young job seekers

Exploring visualisation techniques in VR to enhance memory and engagement for the purpose of introducing professions to young job seekers

A case of improving VR experience by using different levels of fidelity and diegetic and non-diegetic visualisation techniques for early training in the construction field

Eleonora Nava
Student ID: 967612

Politecnico di Milano - School of Design
Digital and Interaction Design

Master’s degree thesis
Academic Year: 2021-2022

Thesis supervisor:

Marina Carulli
Politecnico di Milano
Department of Mechanical Engineering

Thesis supervisor:

Ashis Jalote Parmar
NTNU
Department of Industrial Design

POLITECNICO MILANO 1863
DIPARTIMENTO DI DESIGN

NTNU
Norwegian University of Science and Technology

Preface

This research thesis is the result of the foundation created during the Master's course in Digital and Interaction Design at the Politecnico di Milano and my experience abroad at the university NTNU in Trondheim, Norway. During the stay, I had the opportunity to explore more deeply the psychological aspects and the strategies applied to immersive realities. Specifically, I had the opportunity to write and publish a scientific paper with Professor Ashis Jalote Parmar on the strategies adopted in VR therapies and to collaborate with the IMTEL research team for the VR4VET project (Virtual Reality for Vocational Education and Training). This initiative arose from the need to help and motivate young people in their vocational choice through VR technology. Through this project collaboration, I had the opportunity to adopt the equipment and facilities provided by NTNU's VR Lab to develop my research and test and validate my ideas with the target user.

Abstract

Virtual technology has become increasingly popular and is currently being studied as a tool to enhance learning outcomes across various fields. Using a computer-generated artificial environment can help to increase engagement and interest in the material and contents. The design of VR experiences is trending towards creating increasingly realistic immersive environments. However, no evidence suggests that this approach improves knowledge retention by providing more memorable experiences. The context of the application of this study concerns the practical early training phase of young people who want to pursue vocational education. VR technology can be beneficial to get a taste of the environment, allowing young job seekers to practise in a safe and controlled environment before working in a real scenario. The method of this thesis consists of a systematic review of the state-of-the-art literature concerning the application of different visualisation techniques, including display and interaction fidelity and the integration of diegetic visual elements. The challenge is understanding how realism and diegetic visual elements, seamlessly integrated into the narrative and enriching its details, benefit without lacking usability. The risk is that if implemented incorrectly, diegetic elements may distract attention or increase confusion, providing users with too much or too little information. Therefore, an experiment was designed to compare a low-fidelity scenario with non-diegetic visual elements and a high-fidelity scenario with diegetic visual elements. The experiment confirms previous research that attributes a high level of display and interaction fidelity and the integration of diegetic visual elements to a higher perceptual and cognitive involvement in terms of presence, immersion and flow. The research also contributes to the findings that a high level of visualisation and narration promotes memory and knowledge retention. However, it has been observed that usability is a crucial factor and that the integration of diegetic elements must be combined with a profound investigation of strategies to ensure user feedback. A combination of diegetic visual and audio effects could be a suitable solution. Furthermore, research has shown that a low level of display fidelity and a high level of interaction and integration of diegetic visual elements could achieve similar engagement and learning outcomes. The advantage of using a low-display visualisation would be to expand the accessibility of VR technology and make learning more accessible to a wider audience.

Preface in Italian

Questa tesi di ricerca è il frutto delle fondamenta create durante il corso magistrale di Digital and Interaction Design del Politecnico di Milano e della mia esperienza all'estero presso l'università norvegese NTNU, a Trondheim. In questo soggiorno ho avuto modo di esplorare più a fondo gli aspetti psicologici e le strategie applicate alle realtà immersive. Specificatamente, ho avuto l'opportunità di scrivere e pubblicare un articolo scientifico con la professoressa Ashis Jalote Parmar sulle strategie adottate nelle terapie che usufruiscono della realtà virtuale e di collaborare con il team di ricerca IMTEL per il progetto VR4VET (Virtual Reality for Vocational Education and Training). Questo progetto nasce dall'esigenza di aiutare e motivare i giovani nella loro scelta professionale attraverso la tecnologia VR. Grazie alla mia partecipazione al progetto, ho avuto la possibilità di sfruttare l'equipaggiamento e le strutture del VR Lab della NTNU per condurre la mia ricerca, testare le mie idee e verificarne la validità con gli utenti di riferimento.

Abstract in Italian

La tecnologia VR sta diventando sempre più popolare e attualmente viene studiata come strumento per migliorare i risultati legati all'apprendimento in vari campi. Utilizzare un ambiente artificiale generato dal computer può aiutare ad aumentare l'interesse e l'engagement nei confronti del materiale e dei contenuti. La progettazione delle esperienze VR sta tendendo verso la creazione di ambienti immersivi sempre più realistici. Tuttavia, non ci sono prove che suggeriscano che questo approccio migliori la ritenzione delle conoscenze fornendo esperienze più memorabili. Il contesto di applicazione di questo studio riguarda la formazione professionale dei giovani che vogliono intraprendere un percorso educativo direzionato al lavoro. La tecnologia VR può essere utile per dare un assaggio del vero contesto di lavoro, consentendo ai giovani di poter fare scelte più consapevoli e vivere un'esperienza in un ambiente sicuro e controllato prima di lavorare nel vero contesto lavorativo. Il metodo di questa tesi consiste in una revisione sistematica dello stato dell'arte della letteratura riguardante l'applicazione di diverse tecniche di visualizzazione, inclusa la fedeltà di visualizzazione, di interazione e l'integrazione di elementi visivi diegetici. La sfida è capire come il realismo e gli elementi visivi diegetici possano beneficiare lo scenario senza perdere di usabilità. Il rischio è che se implementati in modo errato, gli elementi diegetici possano distogliere l'attenzione o aumentare la confusione, fornendo agli utenti troppe o troppo poche informazioni. Pertanto, è stato progettato un esperimento per confrontare uno scenario a bassa fedeltà con elementi visivi non diegetici e uno scenario ad alta fedeltà con elementi visivi diegetici. I risultati confermano le ricerche precedenti, che attribuiscono un alto livello di fedeltà di visualizzazione e interazione e l'integrazione di elementi visivi diegetici ad un maggiore coinvolgimento percettivo e cognitivo in termini di presenza, immersione e flusso di coinvolgimento. Inoltre, i risultati mostrano che un alto livello di visualizzazione e narrazione influisce sulla memoria e la ritenzione delle conoscenze. Tuttavia, è stato osservato che l'usabilità è un fattore cruciale e che l'integrazione di elementi diegetici deve essere combinata con una profonda indagine e sperimentazione per garantire adeguati feedback dell'utente. Una combinazione di effetti visivi e sonori diegetici potrebbe essere una soluzione adatta. Inoltre, la ricerca ha dimostrato che un basso livello di fedeltà di visualizzazione, combinato con un alto livello di interazione e l'integrazione di elementi visivi diegetici, potrebbe ottenere risultati di apprendimento e di coinvolgimento simili. Il vantaggio dell'utilizzo di una visualizzazione a bassa fedeltà sarebbe quello di ampliare l'accessibilità della tecnologia VR e rendere l'apprendimento più accessibile a un pubblico più ampio.

Acronymous

VR	Virtual Reality
HMD	Head Mounted Display
UCD	User-Centered Design
HCI	Human–Computer Interaction
UI	User Interface
UX	User experience
DMM	Distance-Independent Millimeter
FOV	Field of View
DF	Display Fidelity
IF	Interaction Fidelity
IMTEL	Innovative Immersive Technologies for Learning
RQ	Research Question
NAV	Norwegian Welfare Administration

Table of contents

01

Introduction

The chapter introduces the research thesis, describing its background and evolution. Beginning with the formulation of research questions, the chapter also outlines the topics on which the state-of-the-art research is based.

Context

This research thesis was conceptualised, shaped and developed during the collaboration with the Innovative Immersive Technologies for Learning (IMTEL) research group at NTNU's VR Lab Dragvoll for the Virtual Reality for Vocational Education and Training (VR4VET) project, which focuses on guidance and counselling of young jobseekers in the field of vocational education and training. VR4VET is an Erasmus+-funded project that started in the post-COVID-19 era, when the need for digitisation increased, as did the unemployment rate of young people. The project aims to develop career guidance methods based on VR technologies to meet the need of young users for adequate information on available career choices. The goal is to provide the possibility to make a more informed choice regarding employment and enable users to explore different realities, get a taste of the professional environment and learn the basics skills.

Motivation

The hypotheses and questions for the research were created independently and separately from the involvement in the VR4VET project, in which the contribution consisted of redesigning the UX and the UI of the project experiences previously created by students. The main objective of the collaboration was to develop standardised guidelines for all VR catalogue experiences within the project to ensure a consistent, accessible, and user-friendly experience. Conversely, the research hypotheses were based on personal reflections regarding the narration and interaction observed during the testing. The development of the thesis entails distinct objectives and research questions related to the different visualisation strategies that can be implemented within VR technology. On the basis of the study conducted on the published paper presented at the IEEE International Conference on Systems, Man, and Cybernetics (SMC) for NTNU [1] in Prague, on techniques for treating mental and emotional disorders with VR therapies, this thesis aims to pursue the exploration of different techniques and strategies applied to immersive environments. The process of this research, starting with the exploration and focus on specific keywords, is outlined in the following sections.

The thesis aims to investigate how different visualisation techniques can affect and impact the cognitive and experiential spheres of users in immersive VR environments.

Concept map

At the beginning of the process, a concept map was created, a graphical tool that helps illustrate the associations among concepts and ideas to organise and capture knowledge and simplify comprehension.

Key topics

The key topics selected as a starting point, shown in Figure 1-1, were pedagogy and learning, training, technology and neuroscience. Pedagogy and learning encompass the theories and practices of education. Training focuses on skill development and knowledge acquisition. Technology is the exploration of the use of VR technology, and, lastly, neuroscience focuses on insights into how the brain processes and learns in virtual environments. By exploring these topics, the goal was to identify best practices for designing VR experiences that enhance learning outcomes and build a deeper understanding of the cognitive processes involved in learning within VR environments and how they can be optimised to maximise educational and early training benefits.

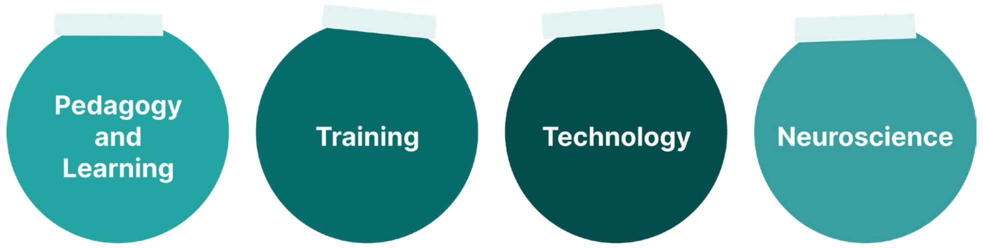
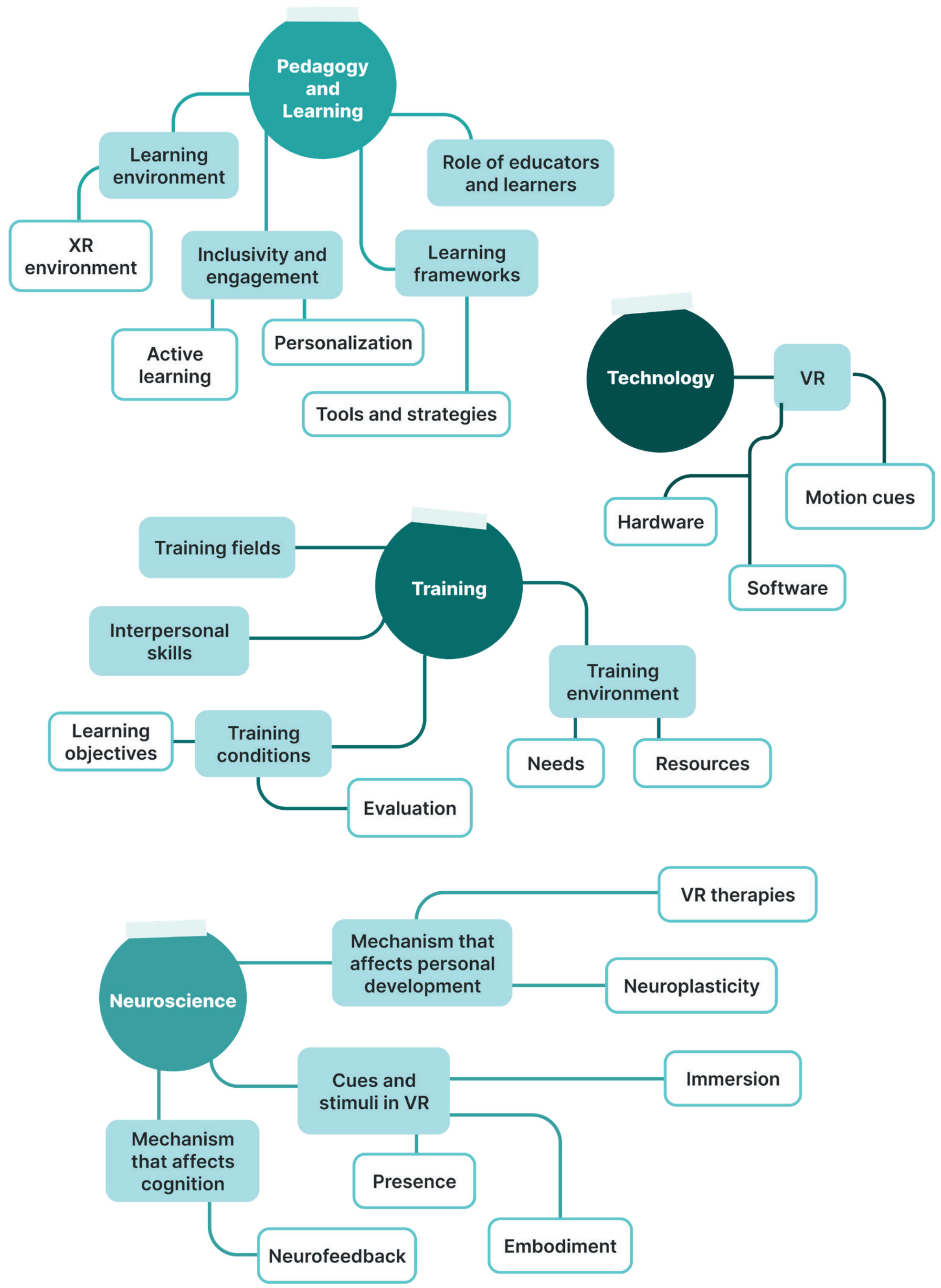


Figure 1-1: First step of the concept map, identify key topics.

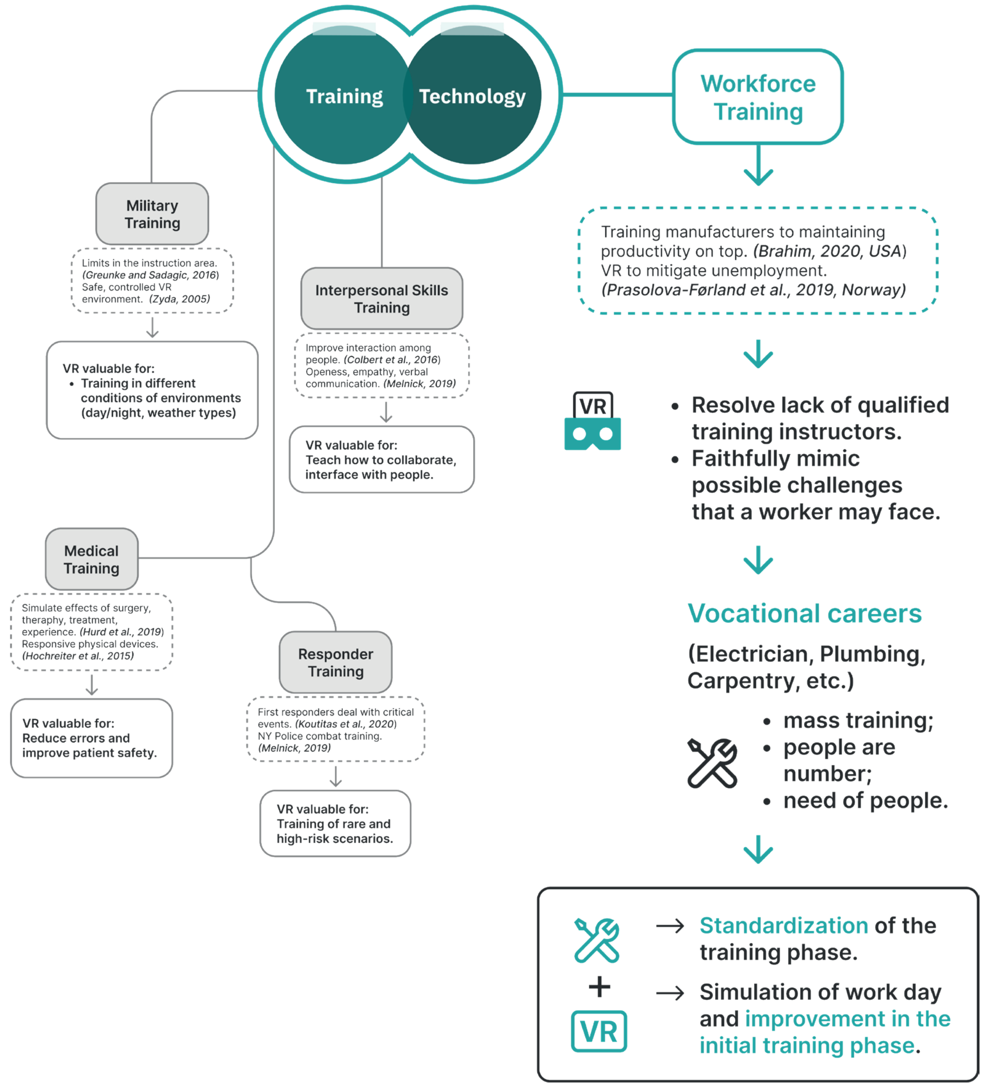
The subsequent stage involved brainstorming, which entailed generating ideas, themes, and questions related to the chosen topics in a global but concise manner. This process lasted approximately two weeks and resulted in the organisation of the information, as shown in the big picture presented in Figure 1-2. The big picture provides an overview of the key meaningful connections that emerged during the brainstorming process. It served as a useful tool for conceptualising the research focus and identifying potential paths for exploration. By examining the interrelationships between the different topics, it was possible to identify knowledge gaps and potential areas for further investigation. Additionally, the big picture helped establish a framework for the research, which guided the selection of research methods.

Figure 1-2: Second step of the concept map, brainstorming.



Following, the key topics were interconnected by establishing relationships and conducting more in-depth research. An example of association is the connection between the keywords "training" and "technology," which involved examining various case studies. This investigation led to choosing the construction sector as the preferred learning environment. The reason behind the choice was the potential of VR to provide standardised instruction to a wide range of users and the shortcomings of the vocational training sector, which faces a shortage of qualified instructors and needs faithful emulation of the potential challenges that workers may encounter in the workplace.

Figure 1-3: Third step of the concept map, connectand create relations between concepts.

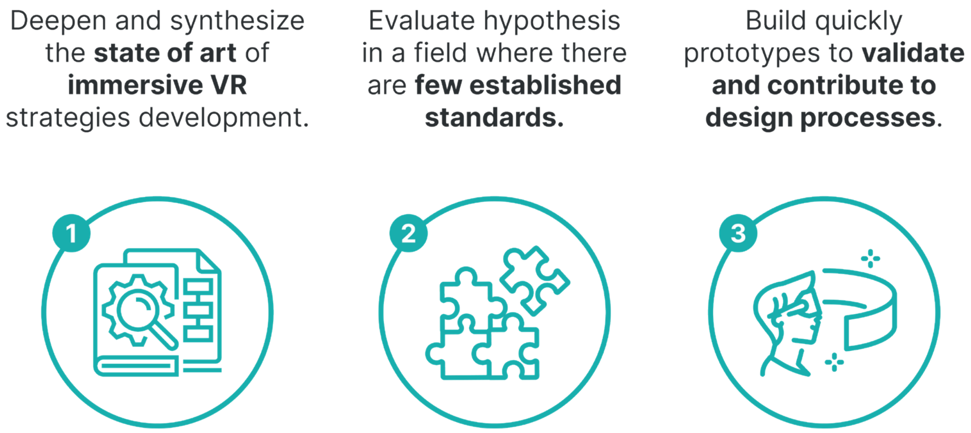


Mapping out the relationships between different concepts and ideas helped to identify the most important topics and subtopics, highlighting knowledge gaps and generating research questions. The missing information and the identified areas of interest were the starting points for the state-of-the-art literature research described in chapter 03 Literature.

Problem description

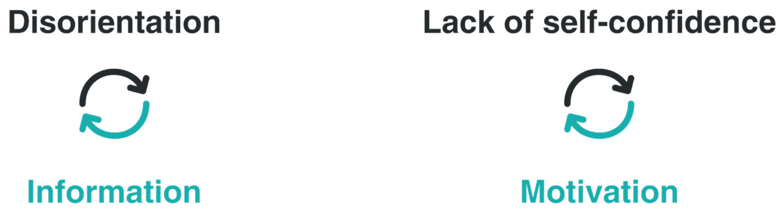
Overall, the problem identified by the brainstorming and conceptualisation of the topic was a need for more design strategies for developing VR education experiences. As there are no established standard guidelines and little research, this thesis aims to contribute to validating ideas and hypotheses through experimentation.

Figure 1-4: Aims of the Master's thesis research.



Specifically, the research question aims to enhance and investigate the hypotheses to address two main gaps identified. On the one hand, the intention of give a "taste" of typical workday routines and activities; on the other hand, the target user should be provided with a more in-depth understanding of the tasks, instructions, and feedback. As the target user during the test often felt lost, disoriented and lacks self-confidence, the spheres to be emphasised and placed at the research's core are information and motivation. These aspects formed the nucleus of the research inquiry.

Figure 1-5: Weaknesses highlighted in the observation phase of the previous VR4VET experiences.



Research questions

The apprehensions surrounding decision-making that can impact the future lives of young job seekers can be mitigated by the VR technology, which aims to help shift the perspective by trying out different experiences in a safe context that simulates reality and allows making mistakes. The thesis objective is to investigate different strategies that enable efficient and effective transmission of information and cultivate the user's confidence and a sense of accomplishment and achievement.

The research question below is:

RQ: "How the level of display and interaction fidelity and diegesis of the UI and visual elements can improve the understading, the sense of presence and the flow of the young job seekers in a VR job taste experience of a vocational profession?"

While more specific sub-questions are:

Sub-RQ1: "Can visual elements and diegesis impact the task performance of the target user and, perhaps, the understanding of the subject matter?"

Sub-RQ2: "How visual realism and display and interaction fidelity can influence the cognitive load and level of immersion while performing a task?"

Sub-RQ3: "Which design techniques can foster memory and learning in a vocational job environment? How can this help users overcome their lack of self-confidence?"

Key areas explored

This thesis investigates how various visualization strategies and techniques affect the user experience in terms of understanding, cognitive impact, and usability for the target audience. The study involved examining the current state-of-the-art literature in relation to display and interaction fidelity, the use of visual diegesis elements, learning processes in VR, and human factors in VR. Subsequently, the knowledge gained from the research was utilized to design a comparative experiment that focused on exploring the impact of display and interaction fidelity levels and visual diegesis on comprehension, immersion, presence, flow, and usability.

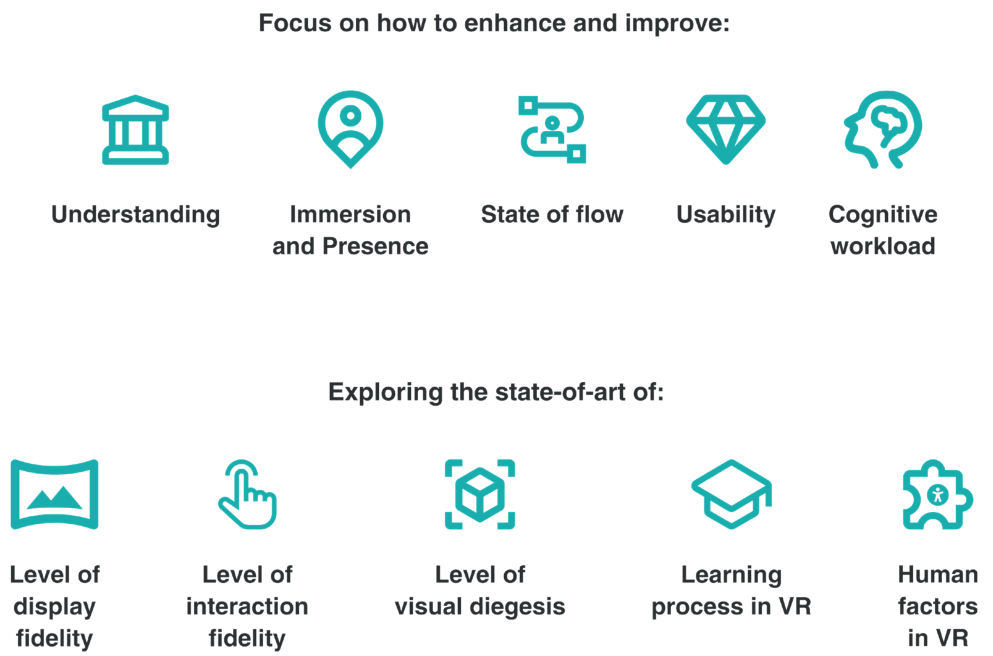


Figure 1-6: Components and factors on which the thesis research focus on.

Research contribution and process

In this section, the intended contribution of this thesis is outlined, with a mention of its contributors and an overview of the process followed.

Contribution

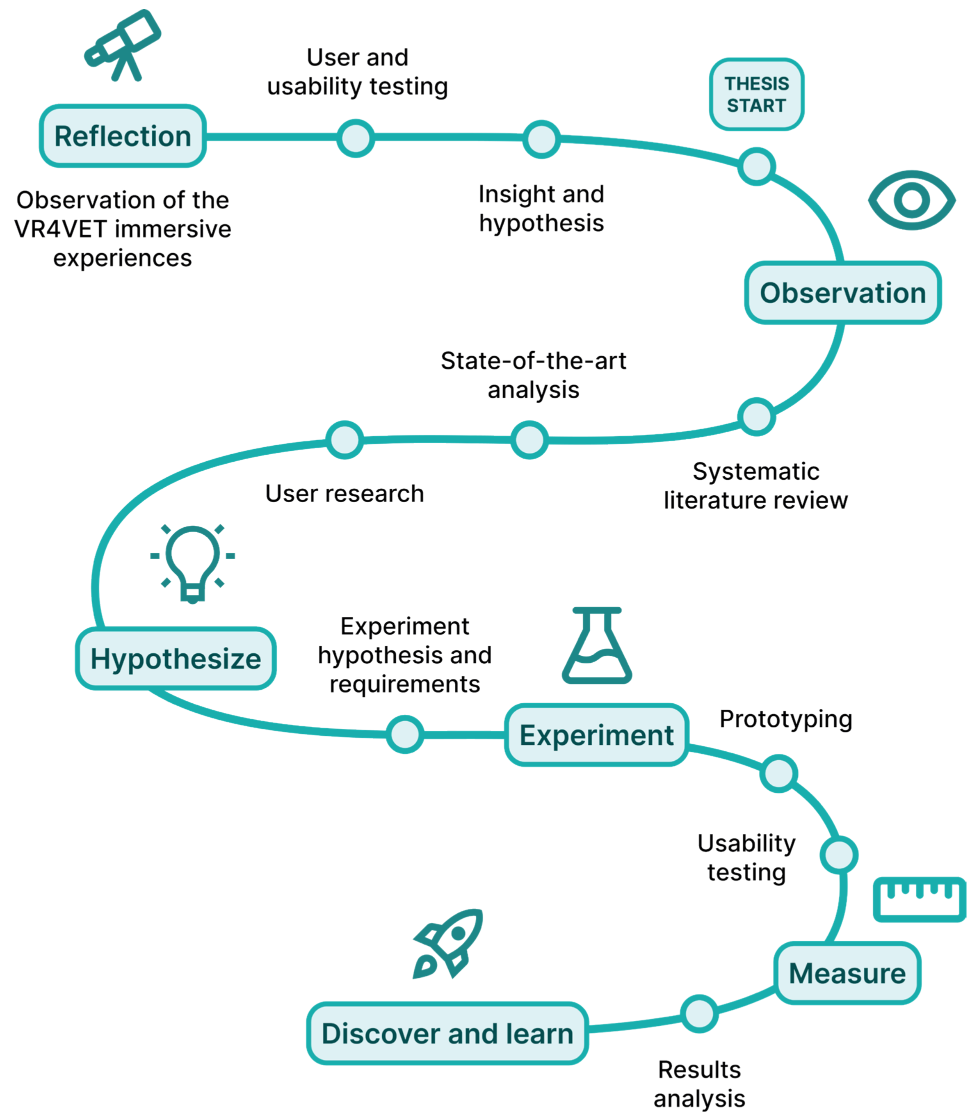
The intended contribution of this research is to provide the design community with practical insights and strategies to enhance the design of immersive virtual environments for learning. By reviewing current literature, exploring the latest advancements in immersive experience design, and considering different perspectives, the aim is to gain an understanding of the key factors that contribute to successful immersive learning experiences. The primary focus of this research is on investigating interactivity, realism and diegesis as crucial elements for achieving enhanced immersion in virtual environments. By examining how these factors can be effectively leveraged in the design process, designers can create immersive learning experiences that are engaging, informative, and effective.

Important to acknowledge the contributors who have provided their expertise to support the development process of this thesis. These contributors include the research thesis coordinators, experts from the construction industry, and researchers and developers from the IMTEL group. A complete list of contributors can be found in the References section.

Process

Figure 1-7 illustrates the process of developing and finalising the research thesis, from the reflection and conceptualisation phase to the discover and learn phase.

Figure 1-7: Thesis's process.



02

Methodology

The chapter overviews the research methodologies and frameworks utilised during the literature review and topic exploration phase. It also describes the methodologies employed to analyse the target user and present the testing results.

Introduction to the literature research methodologies

The coexistence of two approaches guided the development and writing of this research thesis, one approach more scientific-based and one more design-based. Although they both aim to generate knowledge and insights, they differ in terms of structure and control. The scientific-based approach is more systematic and rigorous, while the design research approach is often more flexible, open-ended and iterative. The shared components of both approaches are summarised in Figure 2-1.

Figure 2-1: Synthesis of the approaches' shared components.

- Evidence-based. Both types of research rely on existing evidence, such as academic articles, books, and conference proceedings, to inform and support their findings.
- Critical evaluation of the sources used to ensure their credibility, relevance, and reliability.
- The goal of advancing knowledge and understanding in a particular focus of study.
- Replicability, which means that other researchers can follow the same methods and techniques to verify the findings.

Scientific-based research

Scientific literature research refers to the systematic and thorough examination of existing written materials and sources relevant to a specific research topic or question. It aims to build and advance scientific knowledge by testing theories and hypotheses [2]. The process involves identifying, evaluating, and synthesising the relevant literature to gain a comprehensive understanding of the current state of knowledge and to inform the design and execution of new research.

"A researcher cannot perform significant research without first understanding the literature in the field". [3]

Scientific literature can encompass various sources, including academic journals, conference proceedings, books, theses and dissertations, and reports, and it aims to provide a thorough and critical examination of the existing knowledge on a topic, identify gaps and limitations in current understanding, and inform the development of new research questions and hypotheses. This process involves a systematic and transparent method for searching and retrieving literature and critically evaluating the sources' quality, relevance, and reliability. The output of a literature review is a comprehensive and organised overview of the existing knowledge, which can guide the development of new research, inform hypotheses and research design, and contribute to advancing a field of study.

Figure 2-2: Scientific literature-based research components.

The framework presented in Figure 2-3 summarises the process learned during TPD4505 Design Theory with the tutor Ashis Jalote Parmar at NTNU University during the exchange program. The framework was helpful in the analysis of state-of-the-art research in the field of education with VR.

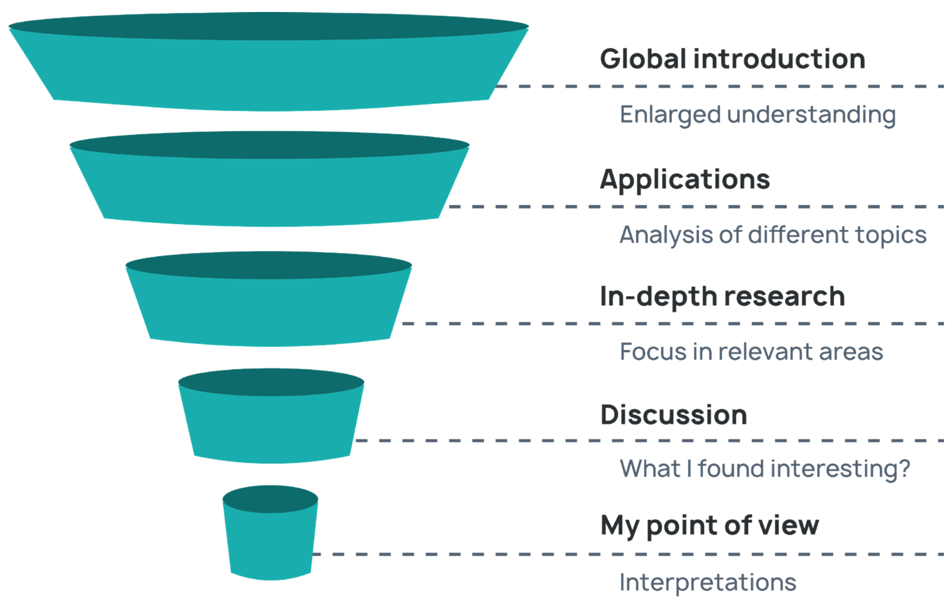


Figure 2-3: Framework used for scientific literature review-based research.

The process can be broken down into the following steps:

1. **Global introduction:** this initial step involves gaining a broad understanding of the research topic by reading and classifying various materials from different fields. Creating a database of all the materials found on the topic can be helpful, and interpreting and summarising their content can aid in developing a deeper understanding.
2. **Problem addressing and research gaps:** in this step, the research question is defined, and specific sub-questions are formulated to guide the investigation. The aim is to identify debates and gaps in the existing knowledge related to the topic.
3. **In-depth research:** once the research question and sub-questions are defined, a deeper investigation begins to answer the research question and gain a more specific view of the topic. This step may involve conducting experiments, surveys, or interviews.
4. **Filtering and interpretation:** in this step, the focus is on filtering the information gathered during the in-depth research and giving importance to the information that helps answer the research question. The information is then interpreted to draw meaningful conclusions.
5. **Personal point of view:** in the final step, the researchers' perspective and their contributions to the research on the topic are visible and presented. A discussion takes place, providing a personal point of view based on the insights gained throughout the research process.

Design-based research

According to the Design Council [4], the main objective of design research is to develop an accessible and reliable body of knowledge that enhances the understanding of design processes, applications, methods, and contexts.

"A designer cannot introduce real improvements without having sufficient information on existing knowledge". [4]

This knowledge is meant to improve the understanding of design and provide practical solutions for design-related problems. In other words, design research helps to establish best practices and effective methods for addressing design issues. Figure 2-4 illustrates the components of design-based research.

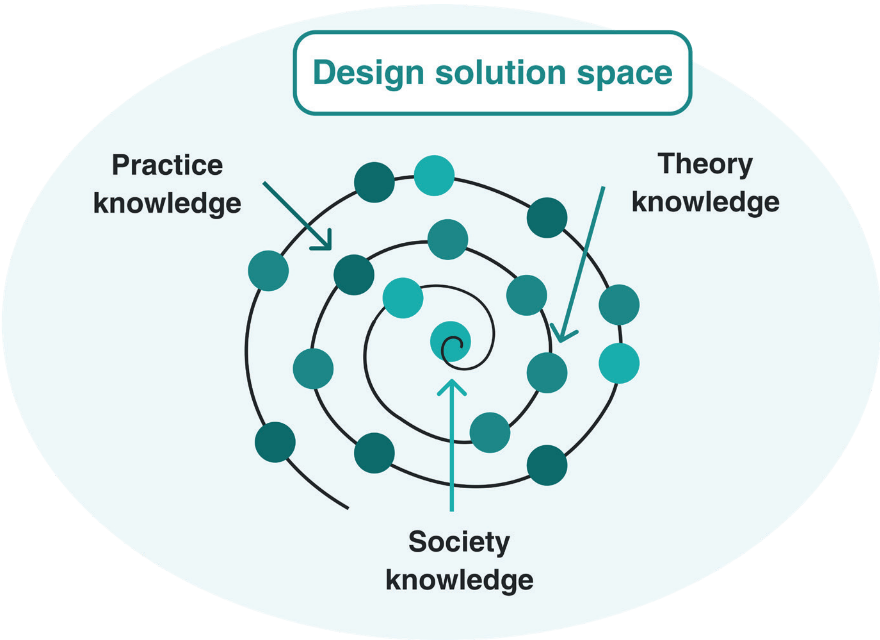
Figure 2-4: Design-based research components.

Design research can be traced back to the early 20th century when the design field emerged as a distinct discipline. Initially, the research referred to the study of the design itself. However, as the field matured, the focus shifted to inquiries as a part of designing and not about design. As design science emerged, which aimed to enhance the design process by applying scientific principles, in the latter half of the 20th century, design research became more interdisciplinary, incorporating perspectives and methods from engineering, psychology, and the social sciences; this resulted in an increased focus on the human aspect of design and the development of new design tools and technologies. Design research continues to evolve and expand, with new areas of inquiry and established areas re-examining in light of new theories, methods, and technologies.

Design solution space

An interesting approach, also investigated during the course TPD4505 Design Theory, is the design solution space. It is a way of thinking about design problems that view the design process as a search for solutions within a space of possible solutions [5].

Figure 2-5: Design solution space approach.



There are two components, the design problem and the design space. The design problem is seen as a set of constraints and objectives that define the design space, while the design space is then explored to identify possible design solutions that meet the constraints and objectives of the problem. This exploration may involve prototyping, simulation, or other forms of experimentation to evaluate the feasibility and effectiveness of different design solutions [6]. The design solution space approach, shown in Figure 2-5, is a valuable tool for designers because it helps to clarify the problem and to explore a wide range of potential solutions, allowing for a more comprehensive and effective design process. It also helps to ensure that the final solution is well-informed and optimised, considering all relevant factors and trade-offs.

Design theory

The subchapter presents specifically the design processes employed to guide the development of the thesis. These include design thinking and user-centred design (UCD).

Design thinking

Design thinking is a non-linear and iterative approach to problem-solving that involves understanding of people's needs and perspectives and utilizing this insight to generate innovative and efficient solutions [7]. The process emphasizes empathy, experimentation, and continuous improvement to design products or services that meet the needs and desires of the users creatively and effectively.

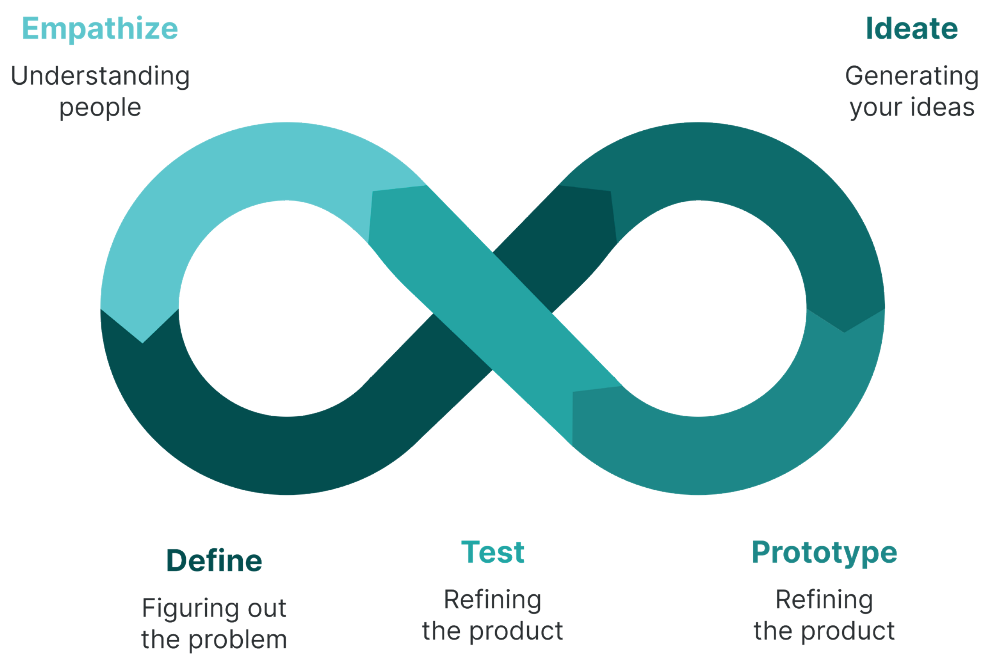


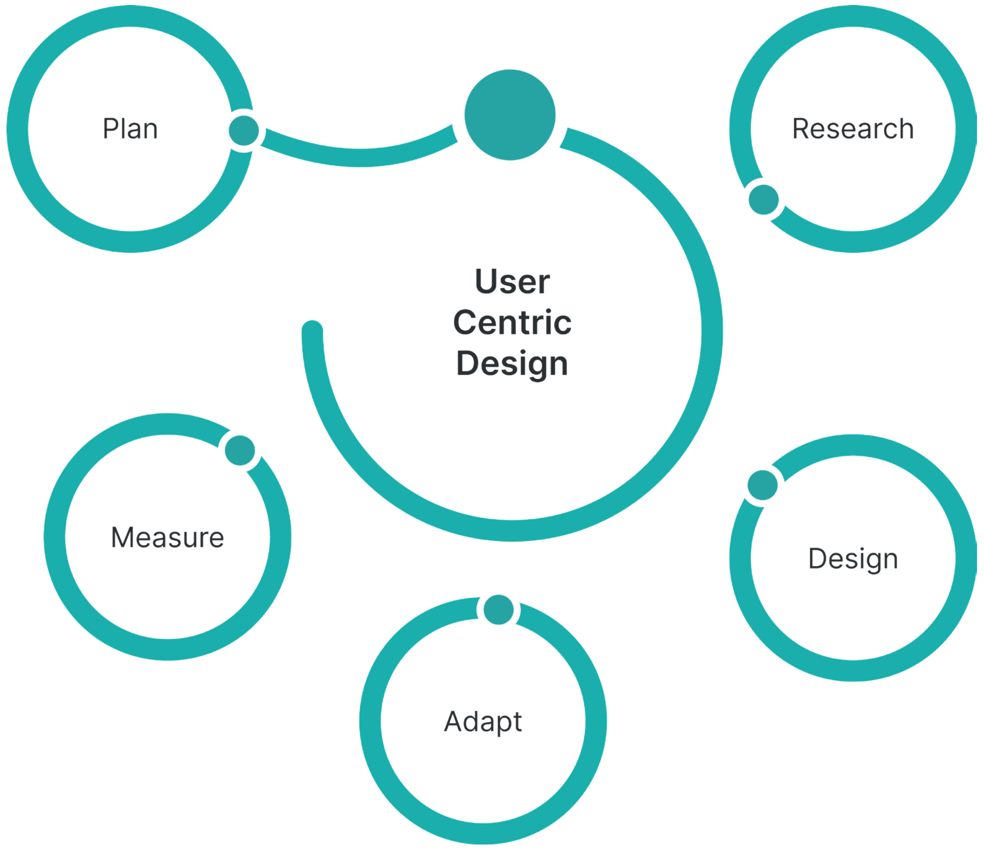
Figure 2-6: Design Thinking model.

The design thinking approach, shown in Figure 2-6, has proved to be a valuable perspective for both research and experimentation processes. When applied to literature research, it can aid in identifying gaps or limitations in existing research, generating new hypotheses, and exploring alternative perspectives. The design-based research approach has also proven beneficial in identifying user needs and developing and testing prototypes to evaluate the effectiveness of design solutions. Furthermore, design thinking can guide the experimentation process by utilizing the empathy and definition phases to identify user needs and research questions, the design and prototyping phases to develop research designs and methods, and the testing and iteration phases to evaluate and refine research results.

User-centered design

Another practical approach at the foundation of this thesis is the user-centered design (UCD), which process is shown in Figure 2-8. While design thinking focuses on unmet needs and develops a creative solution to solve a problem, UCD prioritises integrating user feedback and preferences throughout every step of the product creation, intending to ensure that the resulting design fulfils users' requirements [8]. The standards for UCD are established by ISO (International Organization for Standardization) through the ISO 9241-210 standard [9], which aims to increase the acceptance and efficiency of interactive systems. This approach particularly prioritises the development of interactive systems that are tailored to be effective, enhance user well-being, and promote accessibility and sustainability.

Figure 2-8: User-centered design process.



The principles of UCD form the foundation of this thesis, as the research questions were tailored to meet the needs of the target user and the hypotheses were developed by analysing the user's interaction with a similar product already implemented and utilised by the IMTEL research group in the VR NTNU Lab. The research process began with collecting user insights, perspectives and needs, which were used as the basis for the state-of-the-art research and experiment. This phase was, moreover, extensively developed as this thesis is based on in-depth scientific literature research.

Research methods

This subchapter will look broadly at the methods to collect the data and perform user research. The methods are not presented in any particular order, and later chapters will provide deeper information about their application.

Business Concept Design

A valuable tool for collecting, evaluating and measuring data has been extracted from the book "Testing Business Idea" [10] with the Business Concept Design framework, which is helpful in analysing experimentation. It is a methodology used to create and develop new business ideas that involve a structured process that helps entrepreneurs and business owners systematically identify, evaluate, and refine their business ideas. The approach shows how to test and reduce risk during the testing phase. It helps to give an objective assessment of the strength of the evidence [11] found through the experiment to understand how reliable or unreliable the insights from the tests are.

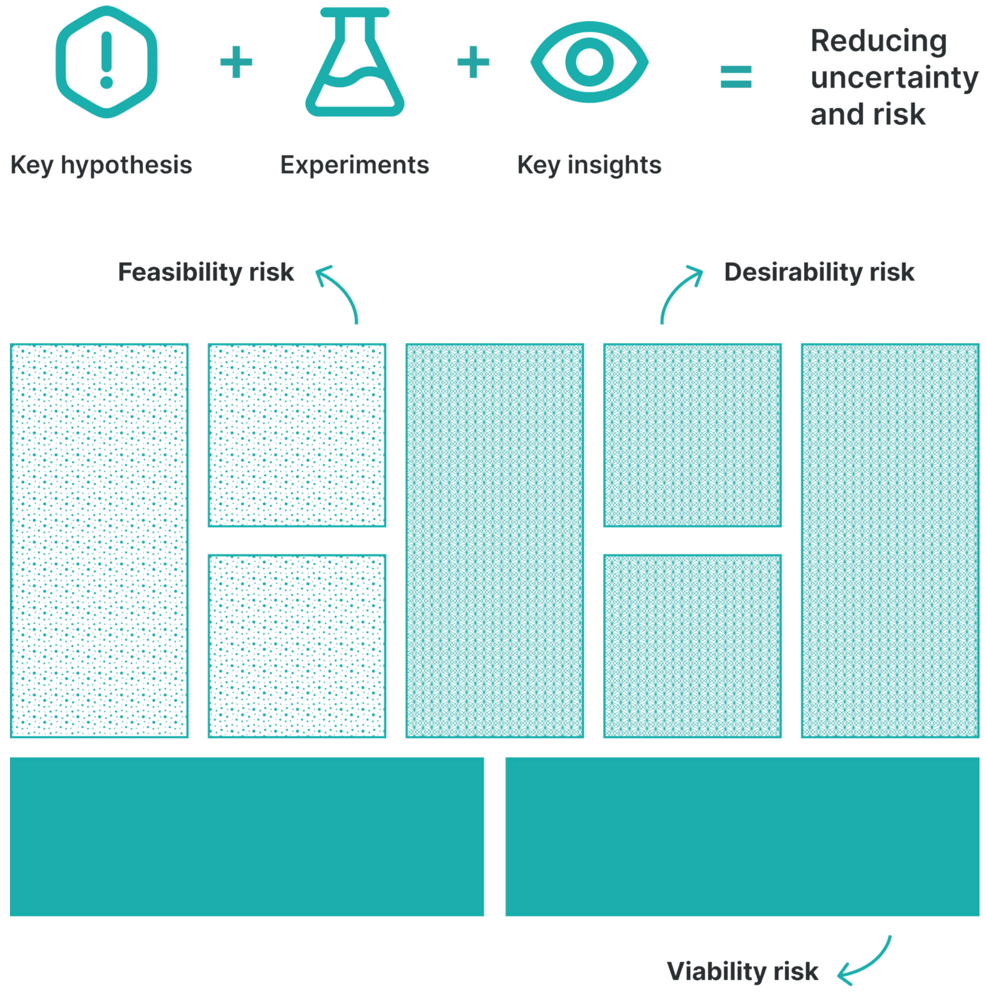
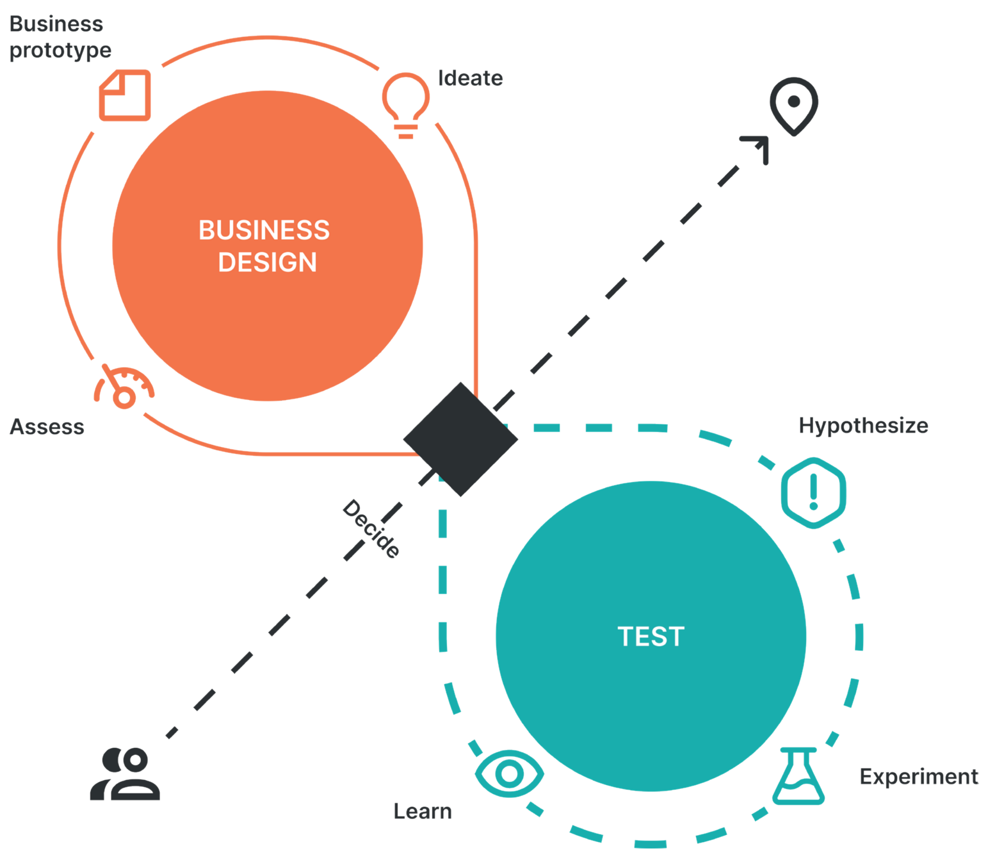


Figure 2-9: Methodology core points useful to the user research part

Figure 2-8
Methodology core points useful to the user research part



Overall, the methods that were used to gather insights are: interviews, direct observation, usability testing, prototyping and post-experience questionnaires. These are explained very briefly below.

Interviews

Interviews aim to deeply understand the user's needs, motivations, behaviours, and attitudes towards a particular topic. It can be conducted face-to-face, over the phone, or through video conferencing. The data collected from interviews can be used to gain valuable insights into the user's experience and inform the design of the product or service.

Observation

Observation method involves observing users interacting with a product or service in their natural environment. This method aims to gather data on how users behave, their needs, and their problems when using the product or service. Observation can be conducted through various methods, including video recording, field notes, and audio recording. The data collected can be used to identify usability issues, design flaws, and areas for improvement.

Prototyping

Prototyping refers to creating early-stage versions of a product or service to test its functionality, usability, and design. Prototyping can be done through various methods, including low-fidelity paper prototypes, interactive digital prototypes, or physical prototypes. The data collected from prototyping can be used to identify design flaws, usability issues, and areas for improvement.

Usability testing

Usability testing involves observing users interacting with a product or service to identify usability issues and gather feedback on the overall user experience. It can be conducted in a controlled environment, such as a laboratory or the user's natural environment. The data collected from usability testing can be used to identify usability issues, design flaws, and areas for improvement.

Post-experience questionnaire

Post-experience questionnaires are about asking users to provide feedback on their experience with a product or service after using it. The questionnaires can be administered online, over the phone, or in person. The data collected from it can be used to identify areas for improvement, measure user satisfaction, and gather insights into the user's experience.

03

Literature research

The chapter encompasses all the scientific and design-based research that establishes this thesis's state-of-the-art literature and theoretical foundation. The research mentions all factors taken into account in the RQs.

Introduction to Virtual Reality

Virtual reality (VR) refers to a computer-generated three-dimensional setting created through software and can be experienced with the help of technologies like head-mounted displays, hand controllers, and other input devices. VR aims to fully immerse the user in a simulated experience that can either mimic the physical world or create new, imaginary environments. This is achieved through 3D graphics, sounds, and other sensory cues, making the experience more realistic. Users can interact with the virtual environment in real time and feel as if they are present within it [12, 13].

Figure 3-1: VR treadmill to walk and run in a virtual environment.

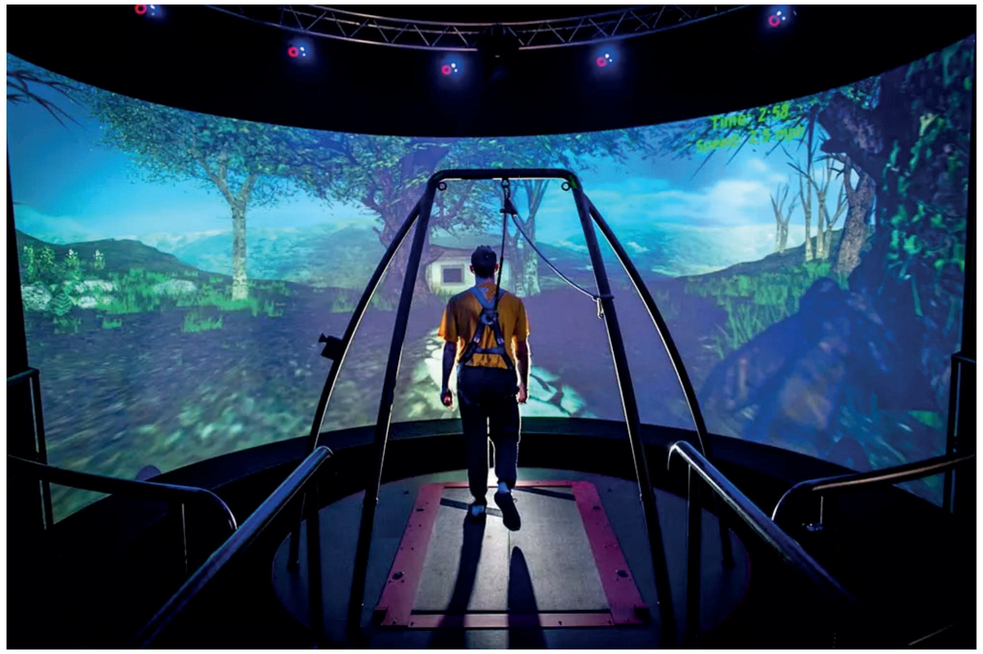


Figure 3-2: VR Head-mounted display.

The VR industry is rapidly advancing and has the potential to revolutionise our interactions with the world around us. The roots of VR can be traced back to the 1950s and 1960s when early pioneers began developing VR systems. However, it was not until the 2000s that VR technology advanced enough to become widely accessible to the public through affordable systems. In recent years, VR has become increasingly popular in various fields, including gaming, entertainment, education, training, medical therapy and rehabilitation, military simulation, and virtual tourism. In the gaming industry, VR provides an unprecedented level of immersion and interactivity, enabling players to experience games more realistically and engagingly. In the medical field, VR is utilised for several purposes, such as pain management, physical rehabilitation, and psychological therapy. Military forces use VR for simulation training to practice and rehearse complex missions in a safe and controlled environment [14]. Jaron Lanier, a pioneer of VR and computer graphics, has defined VR as "a way to transcend the limitations of physical reality and experience a computer-generated world as if it were real". According to Lanier, VR creates a sense of presence by tricking the human senses into believing they are in a different environment through advanced computer graphics, sensory feedback, and interactivity. Moreover, he argues that VR is not just a technology but a new form of art and communication that can revolutionise how we interact with computers and the world around us. VR can change our perception and understanding of reality by providing new perspectives and allowing us to interact with virtual objects naturally and intuitively. In his book "Dawn of the New Everything," Lanier describes VR as a growing ecosystem of technologies that combine to immerse users in virtual worlds. This ecosystem includes gadgets such as goggles, gloves, and floors that scroll, allowing users to feel like they are walking far in the virtual world even though they remain in the same physical spot. Ultimately, the possibilities for VR are endless and continue to expand as technology advances [15]. While VR has shown great potential in various fields, it also has some disadvantages in the educational field. One of the main disadvantages is the potential for motion sickness and disorientation. These issues can be especially problematic for individuals with pre-existing conditions, such as balance disorders or epilepsy. Furthermore, using VR in the classroom may not be suitable for all learners, particularly those with sensory issues or disabilities. To address these challenges, VR designers and educators have established conventions and design methodologies to make VR more accessible and effective in learning [16]. One such convention is using a clear interface with simple navigation and controls to minimise disorientation and motion sickness. Fur-

The VR is progressing rapidly and has the potential to transform different areas and offering new level of engagement and interactivity that was previously impossible.

Jaron Lanier argues that VR is a new form of art and communication. As there are few established conventions, designers can rethink human-computer interaction and shape this evolving field.

thermore, the design of VR experiences in the learning field should consider the needs of diverse learners, including those with disabilities or sensory issues. This can be achieved through the use of different modalities, such as text, audio, and visuals, to provide multiple ways for learners to engage with the content. Another design methodology uses feedback mechanisms to give learners a sense of accomplishment and progress. This can include virtual rewards, badges, or progress bars, which can help motivate learners and enhance their engagement with the content. From a design point of view, the disadvantage is that there are few established conventions and very few experts. VR technology is an entirely open field. However, there is the opportunity to rethink the conventions and patterns of human-computer interaction and be involved in creating this evolving field.

VR technology components

VR technology comprises several components that work together to create a fully immersive experience for the user. The components of a VR system include:

- **Visual display devices** are hardware components that create the illusion of a virtual world. These include head-mounted displays (HMDs), projection systems, and CAVE systems.

The **HDM** is a type of device used for VR immersion that consists of a headset with a display for each eye, providing a 3D visual experience to the user. The HMD, shown in Figure 3-4, is equipped with sensors that track the movement of the user's head, allowing them to experience a sense of presence in the virtual environment.

Figure 3-4: HMD Oculus Quest.

Figure 3-5: CAVE system.

The **CAVE**, in Figure 3-5, is an immersive room that is used to create a fully immersive virtual reality experience. Multiple projections surround the user to create a 360-degree environment, and users may interact with the virtual world using various input devices such as wands, joysticks, or data gloves.

VR treadmill, in Figure 3-6, provide a physical component to the VR experience, allowing the user to walk or run in place within the virtual environment. These physical devices can enhance immersion in the virtual environment and provide a more realistic and engaging experience for the user.

Figure 3-6: VR treadmill.

- **Sensors** are devices that track the user's head and body movement in the virtual environment. This information is used to update the visual display in real time, allowing the user to experience a sense of presence within the virtual environment.

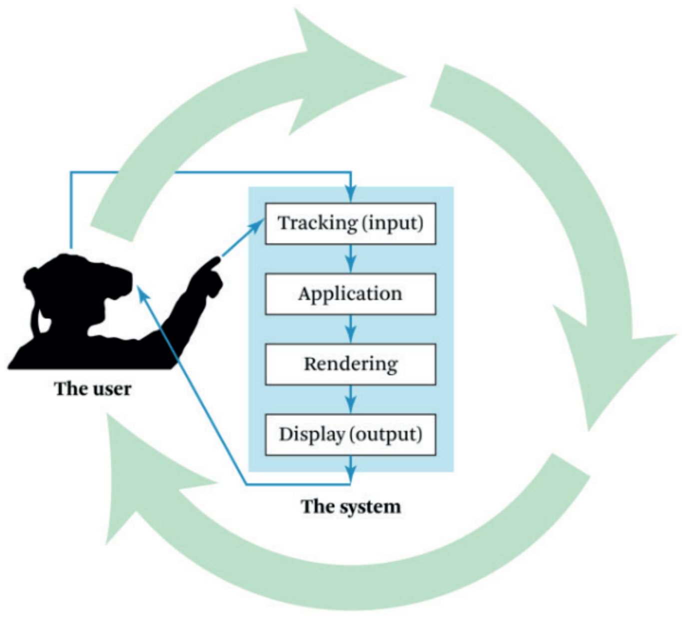
- **Controllers** are devices used to interact with the virtual environment, allowing users to perform various actions, like moving or picking up objects. Examples of VR input methods include hand-held controllers, gloves, voice commands, and gestures.

- **Computer/Processing Unit.** A high-performance computer is required to process the VR content and run the VR software. This computer is responsible for rendering the 3D images in real time and performing other calculations that are required to create the VR experience.

VR simulation loop

The VR simulation loop, in Figure 3-7, is a series of steps that the VR system performs to create an immersive experience for the user, enhancing the sense of presence within the virtual environment, as it respond in real-time to the user's movements and interactions.

Figure 3-7: VR simulation loop.



The steps in the VR simulation loop [36] include the following:

1. **Input.** Collections of data from the user such as where the user's eye, hands are located and button presses.
2. **Application.** The application includes non-rendering aspects, including updating dynamic geometry, user interaction and physics simulation.
3. **Rendering.** The rendering is the computer processes and updates the virtual environment in real time. It is the transformation of a computer-friendly format to a user-friendly format that gives the illusion of some form of reality and includes visual, auditory and haptic rendering.
4. **Output.** The computer displays what is processed on the HMD or other VR visual, auditory or haptic systems.
5. **Repeat.** The VR system repeats the simulation loop, constantly updating the virtual environment based on the user's movements and interactions.

Interaction in VR

Interaction design is the process of designing how users interact with a product, system, or service and involves considering the user's needs, goals, and behaviours and defining how the user will interact with the product. According to Norman [17], interaction design aims to create interfaces that are "invisible" to the user, where the focus is on the task and not the technology. Interfaces should be simple, efficient, and easy to use, and it should not require the user to think about how to use the technology. Similarly, according to Nielsen and Molich [18], the goal is to create "user-centered" interfaces where the focus is on the user and their needs. Interfaces should be designed to meet users' goals and tasks and be easy to use and understand. The goal of interaction design can also be defined as creating an interface that enables the user to achieve their goals efficiently, satisfactorily and errorlessly. Designers should consider the user in different spheres: cognitive, emotional, physical, social and cultural.

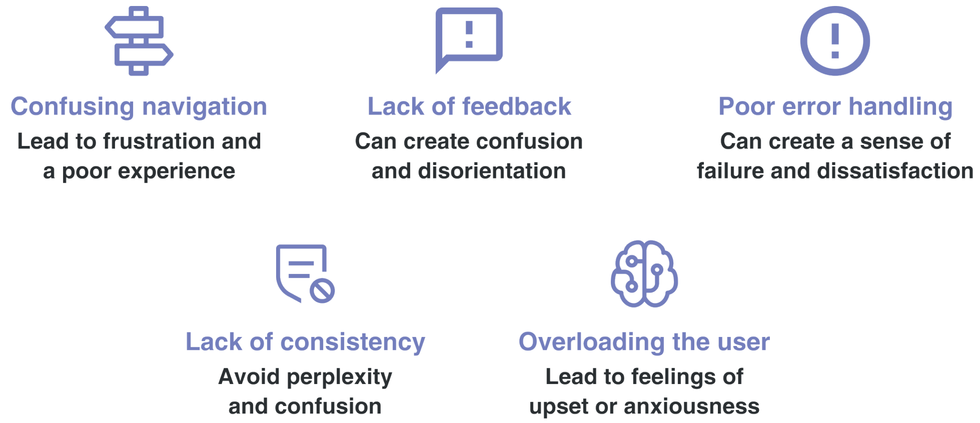


Figure 3-8: Examples of bad experiences in interaction design.

Common UX issues include:

- **Confusing navigation**, an interface with a confusing structure can make difficult for users to find the information or features they are looking for. This can lead to frustration and a poor user experience.
- **Lack of feedback**, not providing feedback to the user can make it difficult for them to understand what is happening or whether their actions have had an effect; this can lead to confusion.
- **Poor error handling**, not providing clear and concise error messages can make difficult for users to understand what went wrong and how to fix it; this can lead to dissatisfaction and a sense of failure.
- **Lack of consistency:** not having consistent design elements and layouts can make it difficult for users to understand how to use the interface. This can lead to perplexity and a poor user experience.
- **Overloading the user with information:** an interface that presents too much information at once can make it easier for users to focus on the task; this can lead to feelings of upset or anxiousness.

Interaction design in VR refers to the process of designing how users will navigate and interact with virtual environments and how the goals will be achieved. A well-designed interaction can distinguish between an immersive virtual environment that feels immersive and natural and tiresome and frustrating]. One of the primary challenges of designing interactions is the need to balance realism with usability. While creating a virtual environment that feels authentic to life, ensuring users can easily navigate and interact with it is also critical. Achieving this balance requires a deep understanding of HCI principles and an ability to translate those principles into the context of a virtual environment [19]. Several key considerations must be taken into account when designing interactions. First and foremost, designers must consider the physical constraints of the VR hardware being used. For example, if users wear a VR headset, they may have limited visibility or mobility, affecting the types of interactions that can be supported. It must also consider the cognitive load users experience when interacting with a virtual environment. Unlike the real world, the immersive environment often has rules and constraints that must be learned and internalised. That can overwhelm users, mainly if they are unfamiliar with VR technologies. To mitigate this, intuitive, easy-to-learn interfaces should be created with clear visual cues and feedback. Another important consideration is the types of interactions supported. Depending on the goals of the simulation, users may need to interact with virtual objects, other users, or a combination of both. Designers must consider how these interactions will be facilitated, including the types of gestures, voice commands, or other input methods used. One of the most exciting aspects of interaction design is the ability to create new types of interactions that are not possible in the real world. For example, immersive environments allow users to manipulate objects with their hands, move through space in unusual ways, or communicate with others through non-verbal cues. Designers must be creative and open-minded when exploring these possibilities while ensuring that the interactions remain grounded in real-world principles of HCI [20]. Ultimately, the success of interaction design depends on the ability to create a seamless and intuitive user experience. This requires a deep understanding of both the technology being used and the users' needs and preferences. By combining these factors thoughtfully and intentionally, designers can create immersive virtual environments that are realistic, immersive, and highly functional and enjoyable to use.

A well-designed interaction for immersive environment balances realism with usability. Designers should consider physical constraints, cognitive load, types of interactions, and creating intuitive interfaces with clear feedback.

This thesis explores mainly three key components of the interaction design process for VR: interactivity, the virtual environment and the user interface. These concepts, explored below, should create a cohesive and immersive experience for the user. To summarise, interactivity refers to the overall level of interaction that the user has with the VR system, the virtual environment defines the immersive digital environment that the user will interact with, and the user interface is the specific design of the visual elements.

Interactivity

In VR, interactivity refers to the capability of the system to respond to the user's actions, allowing for two-way communication between the user and the virtual environment. An essential factor in introducing here, which will be explained in the human factors chapter, is immersion, which is the feeling or sense of being inside and a part of an environment. The combination of the sense of immersion and interactivity is called telepresence, defined by the computer scientist Jonathan Steuer as "the extent to which one feels present in the mediated environment, rather than in the immediate physical environment" [21]. According to Steuer, who conceptualise the diagram in Figure 3-9, a successful VR experience elicits a sense of disconnection from the physical world and engrosses the user entirely in the virtual environment. Although telepresence is a subjective experience unique to each individual, technology can utilise two key factors and their associated properties or sub-factors to enhance the feeling of telepresence. The concept of telepresence in VR refers to the sense of being physically present within the simulated environment, despite being aware of the technology facilitating the experience. The degree of telepresence experienced by an individual depends on various factors, such as the level of immersion, the sensory fidelity of the virtual environment, and the user's cognitive and emotional engagement. Steuer's model of telepresence identifies two fundamental components, vividness and interactivity.

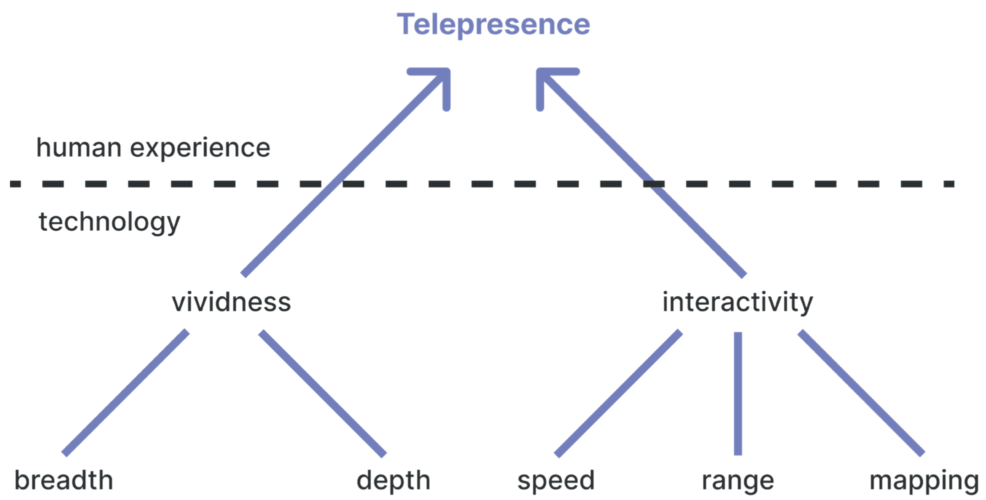


Figure 3-9: Technological variables influencing telepresence.

Vividness means the representational richness of a mediated environment as defined by its formal features, that is, how an environment presents information to the senses. For example, it can be the breadth of information, defined as the number of sensory dimensions simultaneously presented, or depth of information, which refers to the amount and quality of data in the signals a user receives when interacting in a virtual environment. Interactivity, the other facet of telepresence, is the extent to which users can modify the form and content of a mediated environment in real time. Interactivity can range from simple, passive responses to complex, immersive experiences and comprises three subfactors: speed, range and mapping [22].

Speed, Range and Mapping

- **Speed**, refers to the response time and the smoothness of the VR environment. It is about how fast the user is able to move or perform actions within the virtual world, and this immediacy of responses affects the vividness of the environment. This immediacy of response is one of the properties that make even low-resolution video games seem highly vivid. This interactive element is, in fact, important for creating an immersive and believable experience for the user.

- **Range**, which indicates the range of motion and actions that are available to the user within the VR environment. This can include the physical movements the user can make, such as reaching, pointing, and walking, as well as the actions they can perform within the virtual world, such as picking up objects or controlling the direction of movement. A wider range of motion and actions allows for a more immersive and believable experience for the user.

- **Mapping**, that is the process of linking the physical movements of the user to actions within the virtual world. It is the ability of a system to map its controls to changes in the mediated environment in a natural and predictable manner. For example, the mapping of a user's hand movements to actions within the virtual world such as picking up objects or controlling the direction of movement, as well as the mapping of body movements to walking or running within the virtual environment. This interactive element is crucial for creating a seamless and intuitive experience for the user as it allows them to interact with the virtual environment in a natural and meaningful way.

Types of VR interactions

There are myriad interaction techniques that are chosen based on the type of experience one wants to provide, the hardware, and the available technology. These interactions support different types of actions, of which the ones most focused on are selection, manipulation, and locomotion. One the state-of-art [23, 24, 25], the most common types of interactions that can be experienced include:

Point-and-click

Point-and-click, or controller input, which allows the user to select and interact with virtual objects by pointing at them with a cursor or reticle and clicking a button, as shown in Figure 3-10. This type of interaction is commonly used in virtual environments designed to be navigated primarily through a first-person perspective, such as video games, architectural walkthroughs, and other interactive simulations. Point-and-click interactions are simple and intuitive and provide a direct and immediate way to interact with virtual objects or select an area to teleport, as in Figure 3-11.

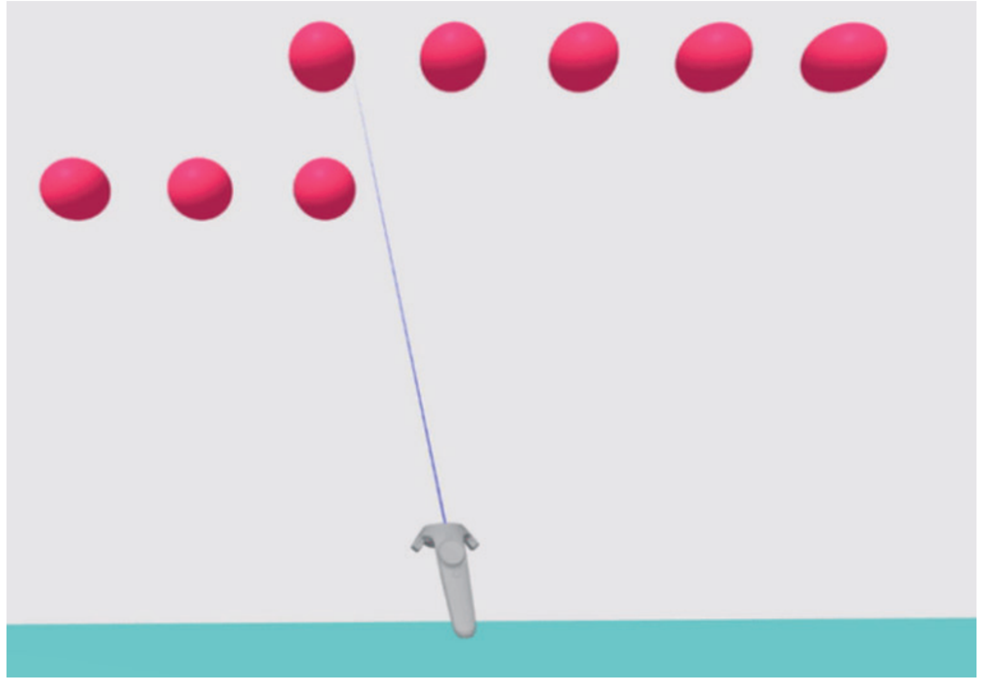


Figure 3-10: Laser pointer for selection.

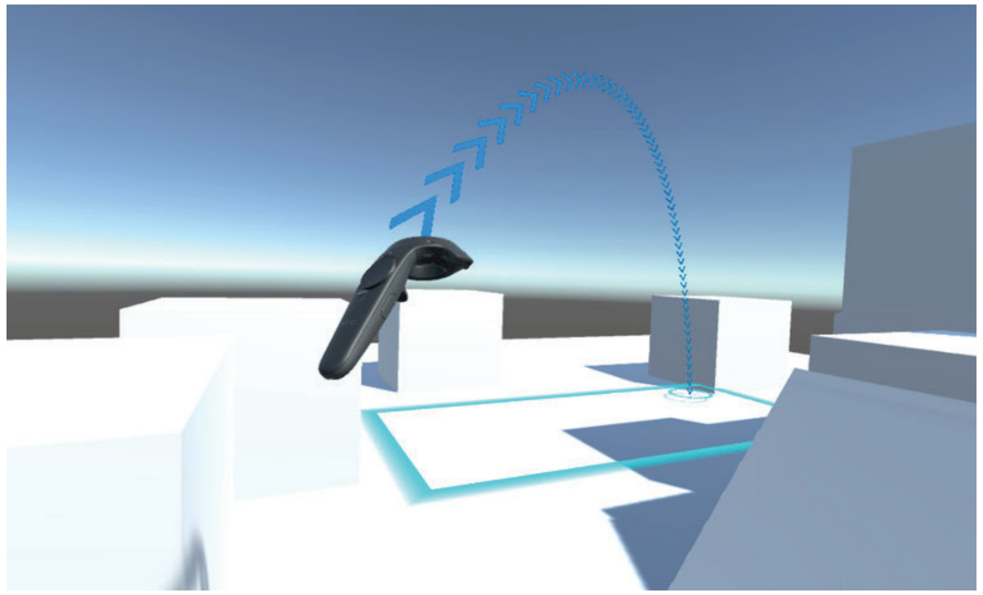


Figure 3-11: Laser pointer teleportation for locomotion.

Gesture recognition

Gesture recognition, as shown in Figures 3-12 and 3-13, is a direct manipulation method that allows the user to interact using hand gestures and body movements. This can include simple gestures such as pointing, waving, or grasping, as well as more complex gestures such as sign language or dance movements. Gesture recognition technology requires a high degree of precision and accuracy and can be sensitive to variations in lighting, background, and the position of the user. This type of interaction is natural and intuitive, similar to how we interact with objects in the real world.

Figure 3-12: Gesture-based selection.

Figure 3-13: Hand tracking for manipulation.

Gaze tracking

Gaze tracking means using eye-tracking technology to track the user's gaze, allowing them to select objects or menu items simply by looking at them, as in Figure 3-14. For example, a VR game might allow players to select objects by looking at them and pressing a button. Usually, the selection area or point is highlighted by an interface element displayed in the virtual world, which position is updated based on the head-pose or gaze of the user, as shown in the analysis of Figure 3-15.

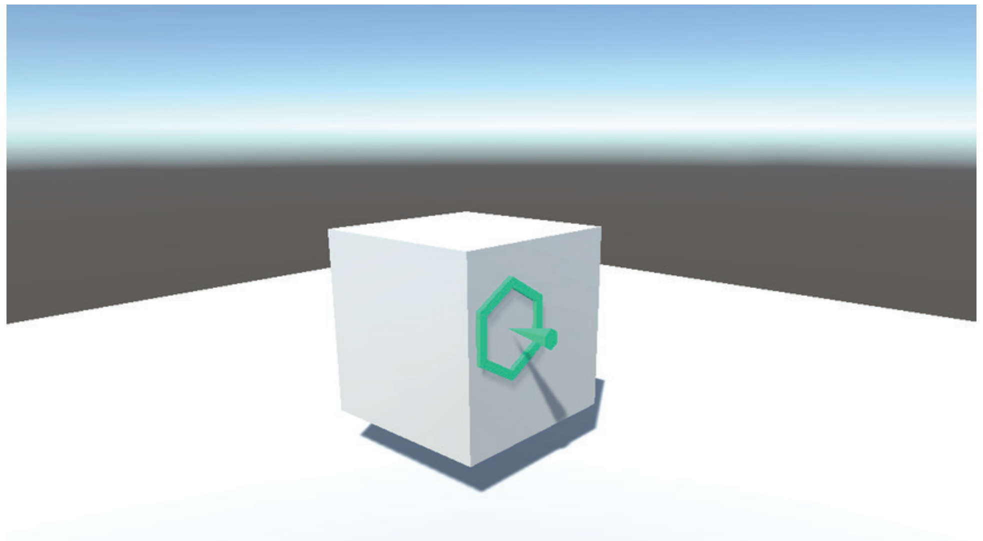


Figure 3-14: Gaze-base selection pointer with a cursor.

Figure 3-15: Eye tracking analysis

Voice commands

Voice commands allow the user to interact with the virtual environment using spoken language commands, as can be seen in Figures 3-16 and 3-17. Voice commands provide a natural and intuitive way to interact with the virtual environment, allowing the user to control and navigate the environment using spoken language, similar to how they interact with the real world.

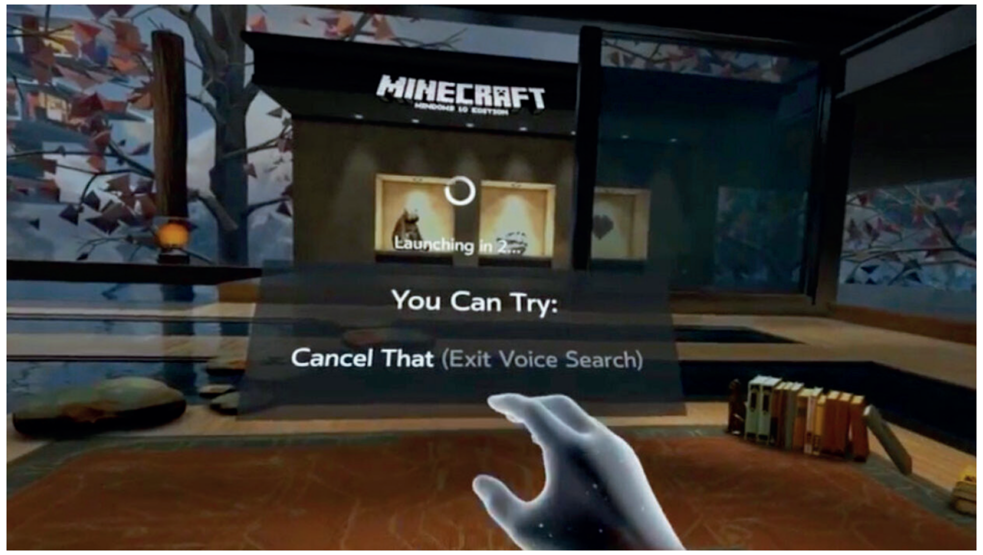


Figure 3-16: Oculus Rift gets voice-controlled search

Figure 3-17: Spell casting VR game.

Brain-computer interface

Brain-computer interface (BCI) is a type of interaction in VR environments that uses signals from the brain to control and interact with the virtual environment, as in Figures 3-18 and 3-19. This type of interaction is achieved by using techniques such as EEG to measure the electrical activity of the brain and then using algorithms to translate this activity into commands or actions in the virtual environment. BCI technology is still in an early stage of development, but it can potentially revolutionise how we interact with virtual environments, especially for people with physical disabilities.

Figure 3-18: BCI HMD.

Figure 3-19: BCI experiment.

Physiological sensing

Physiological sensing uses sensors to measure and respond to the user's physiological state, such as heart rate, respiration, and perspiration, as in Figure 3-20. It can be used to measure the user's emotional state and to provide a more personalised experience. Physiological sensing also allows virtual environments to provide biofeedback to the user, such as providing visual or auditory cues to help the user relax or reduce stress.

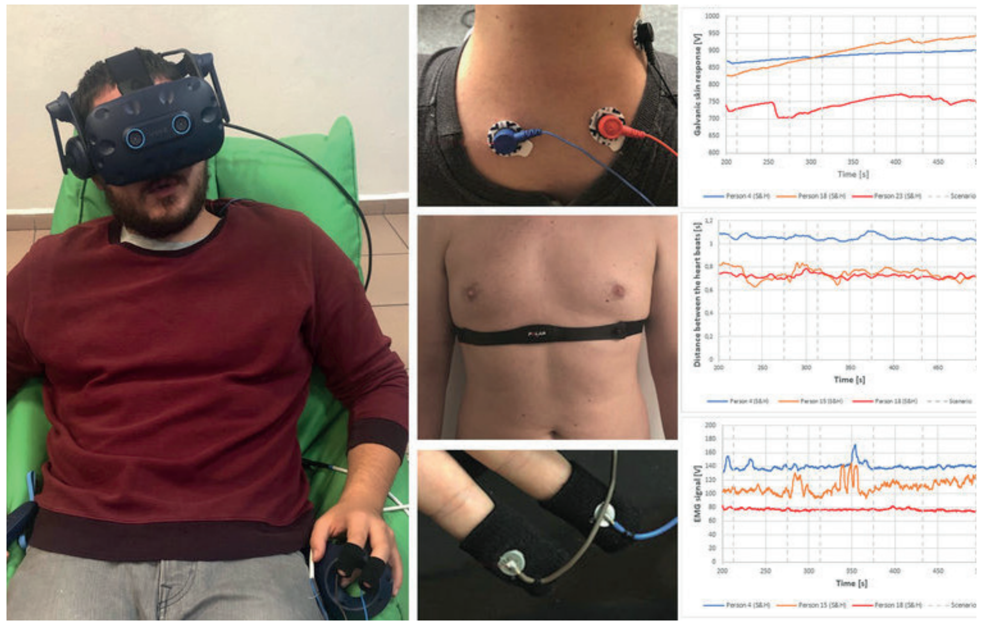


Figure 3-20: Physiological signals acquisition.

Spatial mapping

Spatial mapping, or real movement, allows the virtual environment to be mapped to the user's physical space, enabling more realistic interactions. With the use of an HMD, users can use their body movements to walk around. It is typically accomplished through motion-tracking technology, such as accelerometers, gyroscopes, or optical tracking systems. However, there is a collision risk with real world-object, so systems are now provided with a proximity alert system to safeguard users from collisions, as shown in Figures 3-21 and 3-22. This solution helps mitigate the risk in the absence of an omnidirectional treadmill.

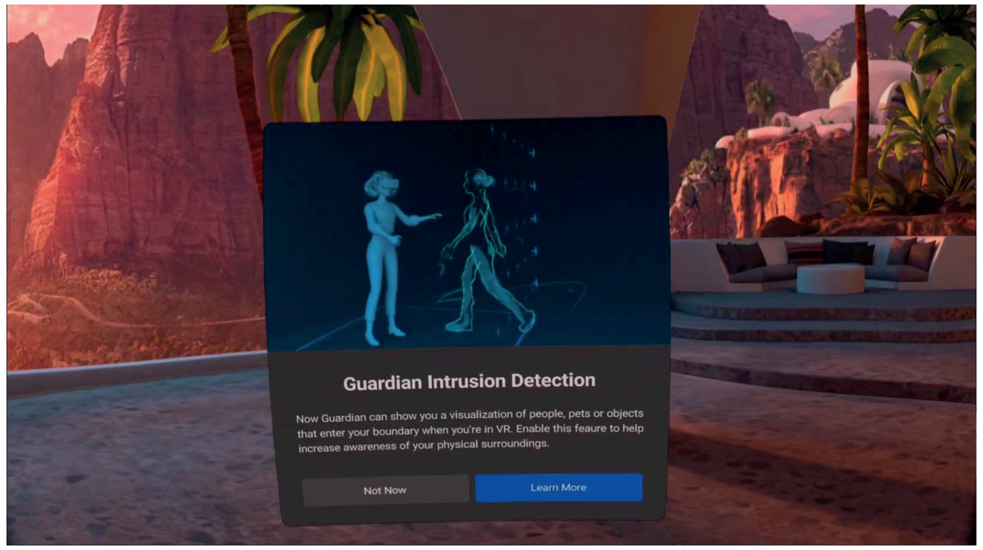


Figure 3-22: Oculus detection system.

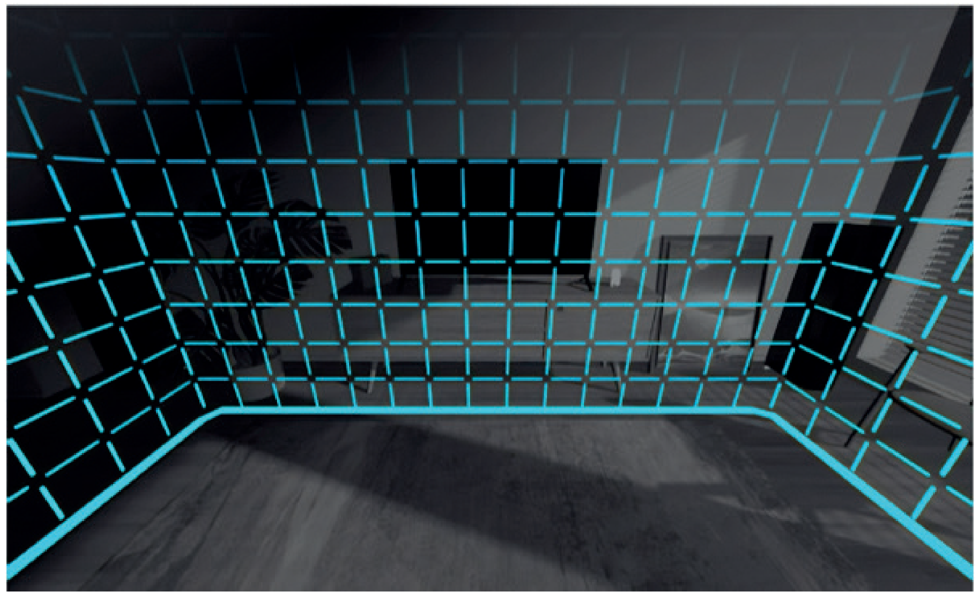


Figure 3-21: Oculus Quest's guardian protection system.

Spatial mapping

Force feedback allows users to feel physical sensations through the use of actuators, which apply forces or vibrations to the user's body, simulating physical interactions such as touch, pressure, and movement. Force feedback can be used to provide feedback for actions such as grabbing and manipulating objects, walking or running, and even firing a virtual weapon, as in Figure 3-23. This type of interaction can be used in immersive virtual reality applications to improve the sense of presence and realism.

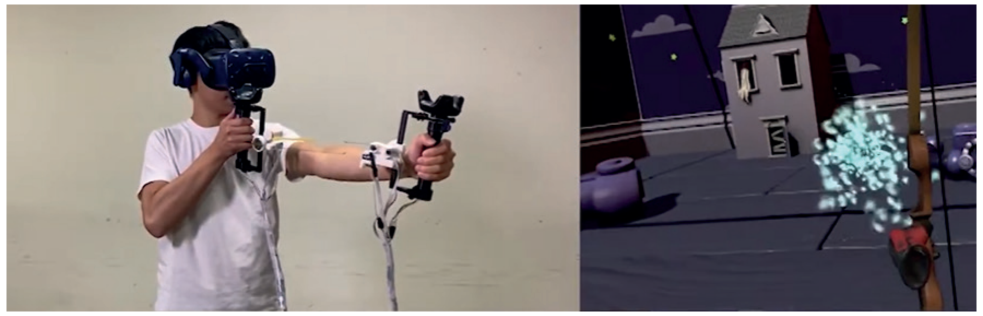


Figure 3-23: Haptic technology to provide force feedback.

The different types of interactions can also be combined in the virtual environment. This can include a combination of touch, gestures, voice commands, physical motion tracking, and other input methods. The goal is to create an immersive and intuitive experience for the user, allowing them to interact with the virtual world in multiple ways that feel natural and seamless. In addition, by incorporating multiple types of interaction, VR applications can provide a more complete and diverse user experience, enhancing the overall sense of presence and engagement within the virtual environment.

Virtual immersive environment

The virtual environment refers to the three-dimensional digital world that the user interacts with and can include the visual and auditory elements that make up the scene. These elements include objects, characters, lighting, sound effects, and physics simulations to create a believable and immersive experience and interactive elements such as virtual objects that the user can pick up, move, and interact with. It can be designed to simulate a wide range of environments or even outer and abstract space. The virtual environment can be designed to respond to the user's actions, such as changing the lighting or weather based on the user's actions and also be designed to adapt to the user's physical space, such as identifying walls and other objects in the real-world space and using them as collision boundaries [26]. The quality of the impacts the user's sense of immersion and realism in the VR experience. A key element to mention here is fidelity, which is the degree of accuracy and exactness with which a VR system recreates and resembles real-world experiences.

The virtual environment is a digital world with interactive elements, including visual and auditory elements and physics simulations. Fidelity is the key to the user's sense of immersion and realism.

Virtual immersive environment

In VR, fidelity is critical for creating an engaging and realistic experience. Research in this field distinguishes between two types of fidelity: display fidelity (DF) and interaction fidelity (IF) [28, 29]. DF is linked to sensory realism, precisely the objective degree to which sensory stimuli in the virtual environment resemble those in the real world. This fidelity largely depends on the quality of visual and auditory elements, including larger displays, higher resolutions, faster refresh rates, and stereoscopic capabilities. High DF can enhance the user's sense of immersion and make the virtual environment look more realistic, but it may also require more advanced hardware and software, adding complexity and cost. On the other hand, IF refers to the degree to which user actions in the virtual environment resemble those in the real world in terms of biomechanics, input, and control. Recent advances in video game systems have allowed for natural, gesture-based interactions that enhance IF. However, there are no clear guidelines for adopting different levels of IF, and this area of research still needs to be explored. While an increase in DF generally leads to a better user experience, particularly in terms of presence, the impact of IF is less clear [30, 31]. High levels of IF may provide greater realism, but low levels of IF may offer familiarity with computer interfaces. Overall, both DF and IF are crucial for creating a compelling virtual reality experience. Researchers continue to explore ways to balance these two types of fidelity to maximize user engagement and immersion.

DF is linked to sensory realism, while IF is the degree to which user actions resemble the real world. High DF can enhance immersion, while high IF provides greater realism. Balancing both is crucial for a comprlling VR experience.

Design the VR environment

Designing a virtual environment involves creating an immersive and interactive experience for the user. Typically it implicates the following steps:

1. **Conceptualization**, which involves defining the overall concept, themes, and objectives of the virtual environment.
2. **Storyboarding**, which means storyboards created to map out the flow of the experience, and to visualize the different scenes and interactions within the virtual environment.
3. **3D modelling**, in which models are created to represent the environment, objects, and characters in the virtual world.
4. **Textures and lighting** are applied to the 3D models to enhance the realism and mood of the virtual environment.
5. **Animation** brings life to the objects and characters in the virtual world, such as moving water, swaying trees, or walking characters.
6. **Interactivity**, implemented through VR controllers, such as hand gestures, gaze tracking, or voice commands, allows the user to interact with the virtual environment.
7. **Testing**, so the virtual environment is tested on various VR platforms to ensure that it runs smoothly and provides an optimal user experience.

VR prototype template

A useful tool for developing a low-fi prototype is the VR prototyping template. It is typically used by designers, developers, and VR specialists to quickly create and test prototypes without requiring extensive programming or technical skills. The template includes pre-built assets and components, such as interactive objects, user interfaces, and navigation controls, which can be combined and customized. This enables designers to focus on the creative aspects of the experience without worrying about the technical details. In addition, the VR Prototyping Template is designed to be user-friendly and intuitive, making it accessible to a wider range of people involved in the VR design and development process.

Figure 3-24: The head-turning radius guidelines.

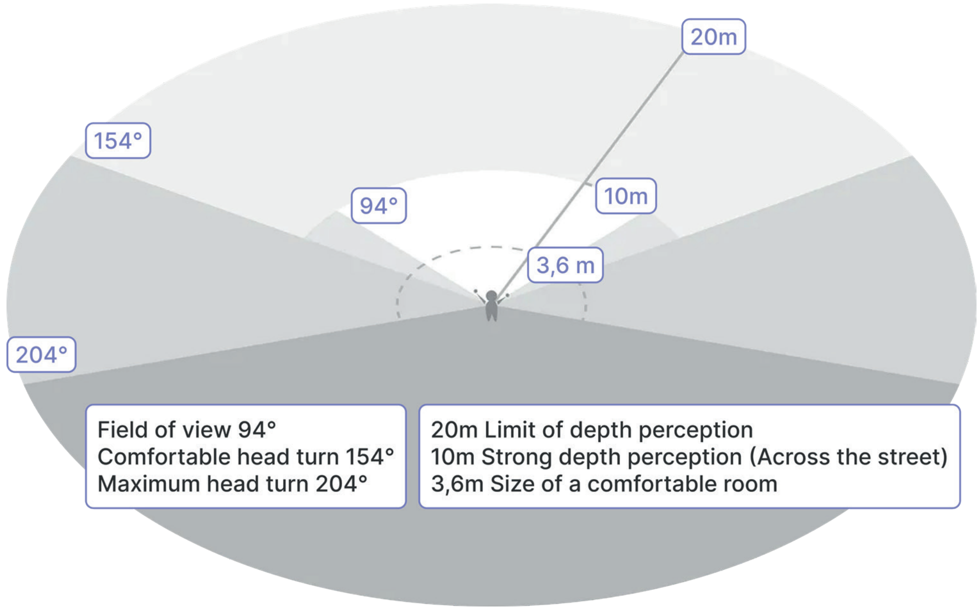
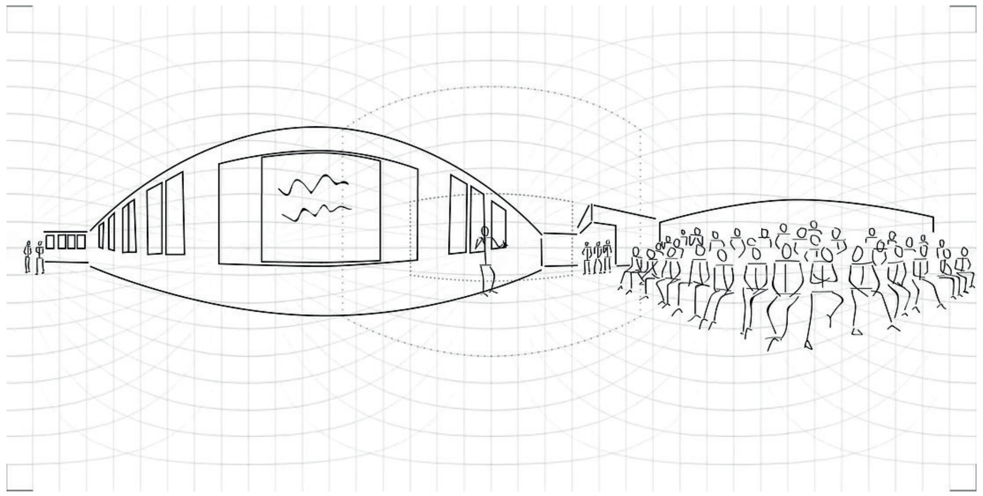


Figure 3-25: 360° panorama grid.



A key feature, shown in Figure 3-25, within the template is the 360° panorama grid, or equirectangular grid, which provides a full-circumscription view of a virtual environment. It maps a 360° spherical space onto a rectangle with 360 degrees equally spaced from left to right and 180 degrees equally spaced up and down. It acts as a canvas for designers to add and arrange virtual objects, such as buildings, landscapes, or other assets, in a full round space. This feature allows designers to preview and iterate on their VR designs, testing and adjusting the placement and behaviour of objects in a virtual environment.

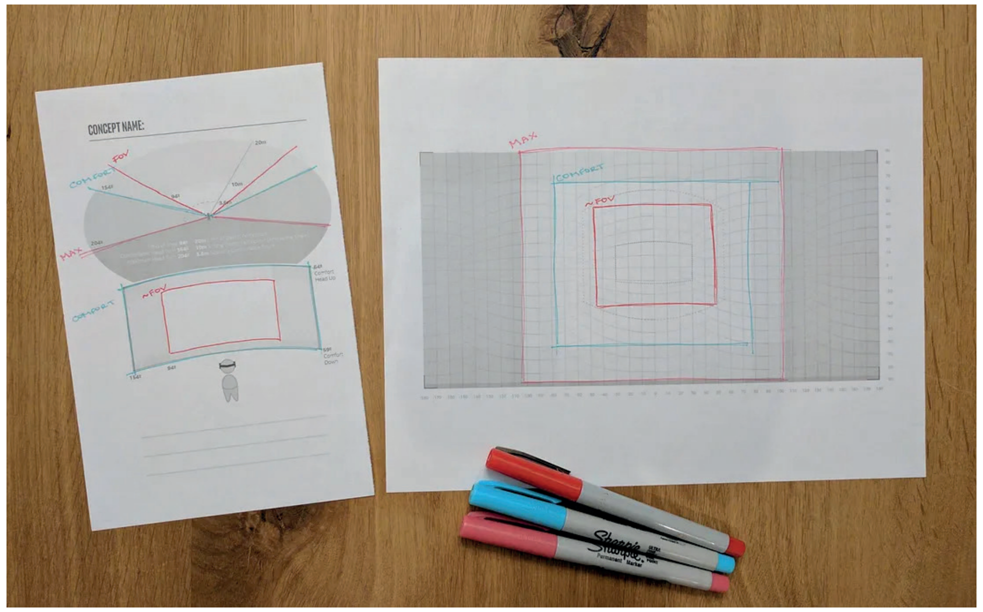


Figure 3-26: Combination of all the templates.

Another concept that should be kept in mind, often forgotten by designers and especially programmers, is that one should not assume that what works for the designer will also work for the user. An approach useful in building the virtual environment is the user engagement by participation scheme is a design approach that involves actively involving users in the creation and evolution of a VR experience.

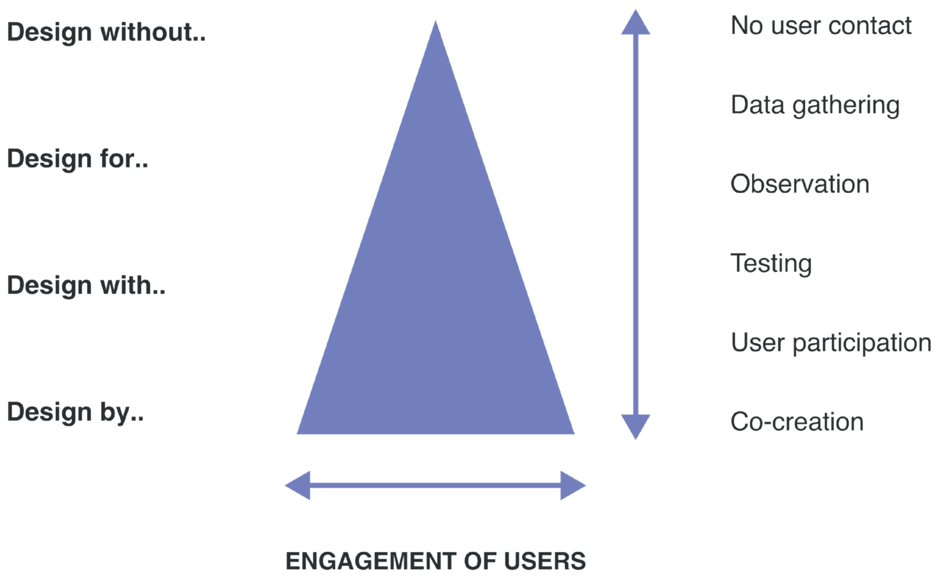


Figure 3-27: Levels for the involvement of users by M. Keitsch [32].

Figure 3-27 shows the different levels of user engagement that designers can apply to involve users in the design process. The level can range from passive involvement to active collaboration, and the appropriate level of engagement will depend on the project's goals, timeline, and resources. It is essential to choose the right level of engagement to ensure that the VR experience meets the needs and preferences of the target audience. By involving users in the design process, designers can gain valuable insights into user needs, preferences, and behavior [32]. When co-creating with users, designers can gather feedback throughout the design process, from the initial concept to the final product. This feedback can be used to improve the design and make it more effective in achieving its goals. Co-creation also provides an opportunity to test different design concepts and features, ensuring that the VR experience is as user-friendly and engaging as possible. Co-creation can take many forms, from user testing to collaborative design sessions. During user testing, users are asked to interact with the VR experience and provide feedback on their experience. This feedback can be used to identify areas for improvement and ensure that the VR experience meets the desired outcomes.

Designers can involve users in VR design. Co-creation provides valuable insights into user needs and preferences. Feedback enhances the design, and testing identifies areas for improvement.

User Interface

When designing UIs for VR, it's automatic to rely on traditional design principles and conventions. However, many of these principles may not be suitable for VR environments, and VR developers have found that many of these conventions are no longer applicable. That is because VR environments provide a full 360-degree environment for the user to interact with rather than a limited space within their field of vision. As a result, designers should create interfaces that essentially embody the user in 3D space. To understand the challenges a UI designer faces in VR, it is essential to consider both the potential opportunities and the potential obstacles to be confronted with.
Most modern UI Guidelines for VR focus on specific design principles:

Intuitiveness and minimalist design

To enhance the user experience, it's essential to have a user interface that is both intuitive and easy to use. Users should be able to interact with the virtual environment without having to spend too much time figuring out how it works. Clear and concise instructions and feedback can be fundamental in achieving this objective. Minimalist design, on the other hand, refers to an interface that is simple and uncluttered. It might involve using a clean and simple color palette, minimal text or visual elements, and an unobtrusive layout which aims to reduce cognitive load and enhance navigation for users. Simple and uncluttered design elements can make it easier for users to understand the environment, and improve their spatial memory and navigation [33]. Moreover, an intuitive virtual environment can lead to better user engagement and satisfaction. When users can easily interact with a virtual environment, they're more likely to explore and engage with it. This can create a positive user experience, leading to greater satisfaction and a higher chance of repeat usage.

Consistency

Consistency refers to following established rules and conventions to maintain a uniform user interface, navigation, and feedback mechanisms. In addition, it ensures that virtual objects and characters within the environment behave predictably and logically. By following these established rules and conventions, VR developers can create more immersive, accessible, and user-friendly experiences for their users. Maintaining consistency in VR interactions is important for several reasons [34]. First, it helps users feel more comfortable and familiar with the VR environment, leading to a better overall user experience. Second, it reduces the cognitive load on users, as they don't have to constantly learn new rules or conventions within the VR environment. Finally, consistency can improve the overall usability and accessibility of the VR experience, making it accessible to a wider range of users. Consistency can also lead to greater engagement and enjoyment among users. When users are familiar with the rules and conventions of a VR environment, they can focus more on the experience itself rather than trying to figure out how to interact with it. This can create a more immersive and enjoyable experience, leading to greater satisfaction and a higher likelihood of repeat usage.

Universal Recognition of Affordances

In VR, affordances refer to the visual and functional cues that provide information about how an object or interface can be used. They are based on the idea of perceived opportunities for action within an environment [35]. For example, in a VR environment, affordances can include the ability to pick up and manipulate virtual objects, move through the environment, or interact with other virtual characters. Studies have shown that users are better able to recognise and utilise affordances in VR environments than in traditional computer interfaces [36]. This is due to the increased immersion and realism of VR environments, which makes it easier for users to understand the potential actions available to them. Moreover, research has found that users are able to transfer their knowledge of affordances from the physical world to VR environments, which makes it easier for them to understand and utilise the affordances within the virtual environment.

Providing informative feedback

Feedback refers to the information provided to users about their actions, behaviour and interactions within a VR environment [37]. This can include positive and negative feedback and can take the form of visual, auditory, or haptic cues and help the user understand the results of their actions and make informed decisions. Informative feedback plays a crucial role in creating a sense of presence in virtual environments, and one way to provide informative feedback in VR interactions is through visual cues. This can include using colours, shapes, and animations to indicate different states or actions within the VR environment. For example, it can use a green colour to indicate that a user has successfully completed a task or a red colour to indicate that a user has made an error. Auditory cues, including sound effects, music, and spoken feedback, can also convey different states or actions. For example, it can use a sound effect to indicate that a user has successfully completed a task or spoken feedback to indicate that a user has made an error. Haptic feedback is another way of providing informative feedback in VR interactions, which uses vibrations and other physical sensations to indicate different states or actions within the VR environment [38]. For example, an experience may use vibrations to indicate that a user has successfully completed a task or that a user has made an error.

Accessibility

The UI should be designed to be accessible for users with different abilities, like those with visual, auditory, motor, and cognitive impairments. This can be achieved by providing alternative forms of interaction and feedback, such as voice commands, haptic feedback, and high-contrast UI elements. One way to improve accessibility in VR is, in fact, through the use of assistive technology. For example, individuals with visual impairments can use screen readers or text-to-speech software to access VR content [39]. In contrast, individuals with motor impairments can use alternative input methods such as eye-tracking or voice recognition. Fundamental is to design VR experiences with accessibility in mind from the beginning. This includes providing clear and consistent navigation, using high-contrast colours, and offering multiple ways to interact with the virtual environment. Additionally, inclusive design practices can be implemented to ensure that users' diverse needs and abilities are considered throughout the design process.

Visibility and intended viewing distance

Visibility refers to how clearly and easily the UI elements can be seen and understood within the VR environment. In order to ensure good visibility, it is important to consider the size, shape, and color of the UI elements. For example, the UI elements should be large enough to be seen clearly, but not so large that they take up too much space in the user's field of view. Additionally, the color and contrast of the UI elements should be carefully chosen to make them easily distinguishable from the background. Intended viewing distance refers to the distance between the user and the UI elements within the VR environment. In order to ensure that the UI is easily viewable, it is important to place the UI elements at a distance that is comfortable for the user to see and interact with [40]. For example, if the UI elements are too close to the user, they may be difficult to focus on or interact with. Conversely, if the UI elements are too far away, the user may need to strain to see or interact with them. Additionally, the intended viewing distance may be different for interactive content versus passive content.

Human factors in VR

This subchapter is dedicated to illustrating the characteristics of human factors applied to vr technology.

Human factors and application in VR

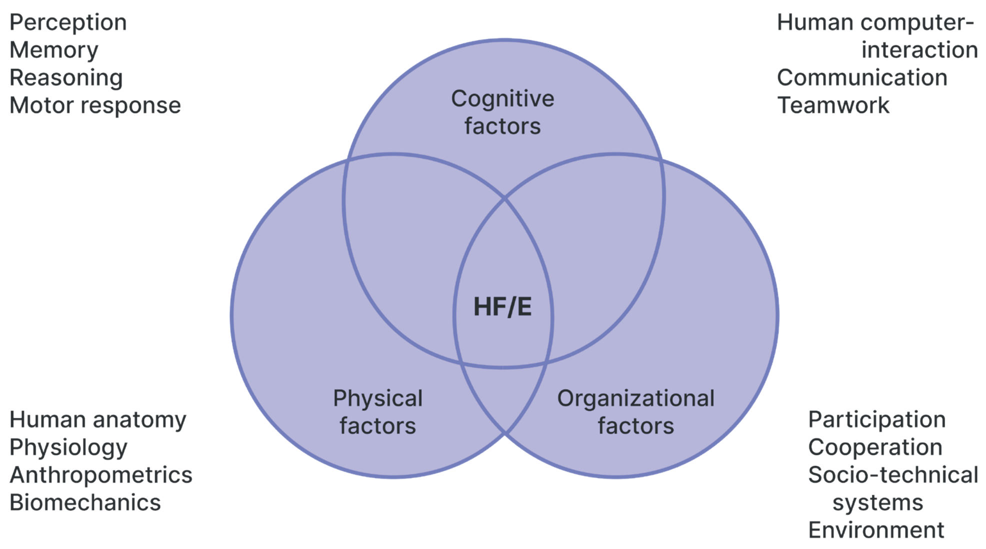
Human factors, or human factors engineering, is about applying knowledge of human capabilities, behaviours and limitations that can be physical, sensory, emotional, or cognitive to product design and development. However, the term is also used synonymously with ergonomics making the two disciplines become one, as ruled by the International Ergonomics Association (IEA), which defines human factors or ergonomics as "the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and methods to design in order to optimise human well-being and overall system performance" [41]. Human factors and ergonomics are closely related disciplines, but they differ in scope and focus. Human factors is a broader field that encompasses various aspects of human behaviour, human-centered design, and performance, including cognitive, physical, and social factors. Its aim is to understand how people interact with products, systems, and environments and how to design them to be safe, efficient, and satisfying. On the other hand, ergonomics is a subfield of human factors that specifically focuses on the design of products, systems, and environments to optimise human physical performance and comfort and minimise the risk of injury and discomfort. It takes into account factors such as biomechanics, anthropometrics, and work physiology and aims to ensure the best possible fit between the individual and their work environment [42, 43]. In summary, while human factors is

Human factors is about designing products, systems, and environments that are safe, efficient, and satisfying for people to use by considering their capabilities, behaviors, and limitations.

a multidisciplinary field that applies knowledge from various fields to optimise human-system interaction, ergonomics is more focused on designing the system, equipment, and environment to match the physical capabilities and limitations of the user.

The IEA [41] identifies three main domains of human factors in design:

Figure 3-28: Macro domains in human factors area.



- **Physical factors** pertain to the characteristics of the human body's physical movement, including anatomy, anthropometry, physiology, and biomechanics. These factors are primarily relevant to domains such as material handling, operational posture, workspace design, repetitive actions, operational injuries, safety, and health.

- **Cognitive factors**, on the other hand, focus on the psychological processes involved in the interaction between human beings and other factors in a system. These factors include perception, memory, reasoning, and motor response, and they impact interactions among humans and other elements of a system. Cognitive factors are primarily relevant to domains such as cognitive load, decision-making, human-machine interaction, human reliability, skill transfer, and work pressure.

- **Organizational factors** refer to the optimization of sociotechnical systems, including their organizational structure, policies and regulations, and management processes. These factors primarily pertain to areas such as communication, community work efficiency, staff management, team collaboration, virtual teamwork, and work design.

When designing for VR, there are key elements of human factors and ergonomics to be considered [44, 45]. These include:

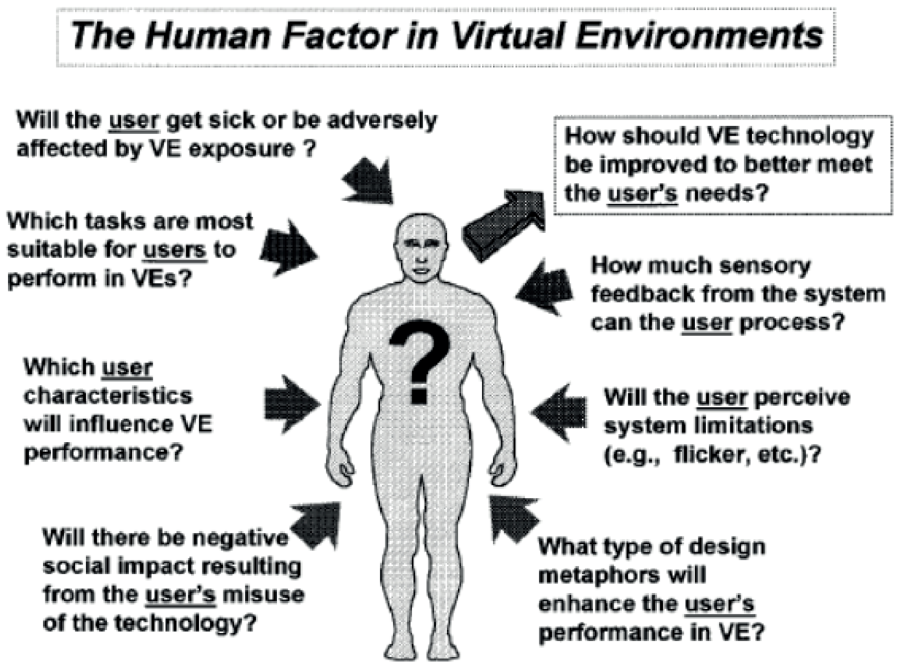


Figure 3-29: Human factors in virtual environments.

- **User comfort**, which involves reducing discomfort and physical strain while using the VR system, such as eye strain, neck strain, and motion sickness. Designing controllers and interfaces should take into account human physiology, including hand size, reach, and eye movement.

- **Usability**, which involves ensuring that the VR experience is easy to understand and use by providing clear instructions, intuitive controls, and a logical information architecture. User-centered design principles should be applied, as mentioned in the previous section on the usability of interfaces, and users should be provided with relevant information, feedback, and cues.

- **Perception and cognition**, which involves understanding how users perceive and interpret VR environments, including presence, immersion, and user engagement. Creating intuitive and immersive interfaces that respond to the user's movements and actions can enhance user experience.

- **User accessibility**, which is about considering the needs of users with disabilities and providing options for those who are visually impaired or have mobility issues.

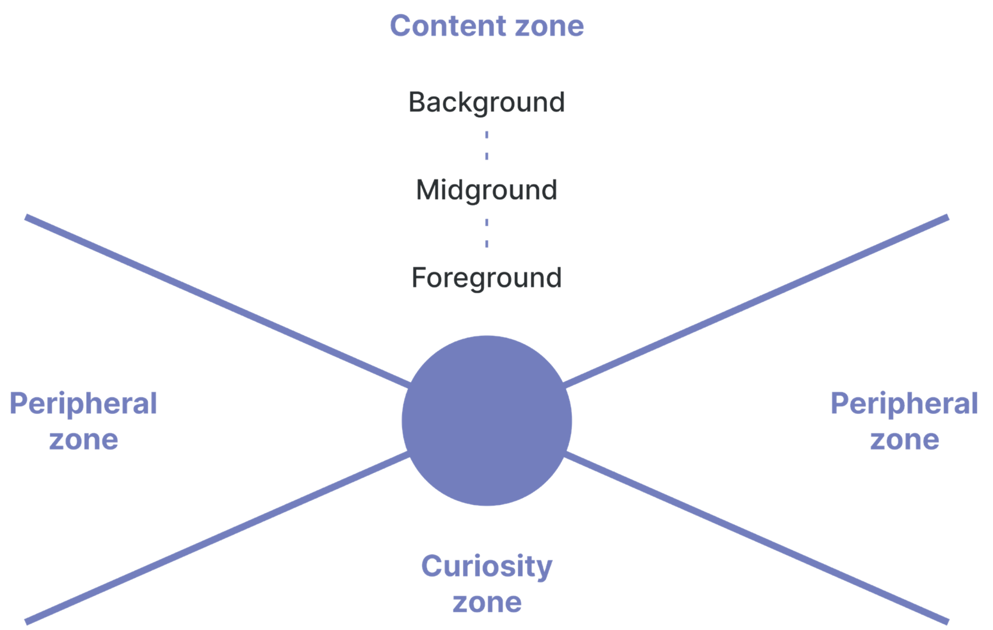
- **Workload**, which involves managing the cognitive load on users to prevent mental fatigue and overload.

- **Physical safety**, that is about minimising the risk of injury or strain, such as reducing the risk of tripping or colliding with objects in the virtual environment, cable management, and ensuring users' physical safety.

User comfort

Optimizing virtual environments for human comfort and well-being requires an understanding of human ergonomics. This involves considering various factors related to human physiology, such as user posture, hand and finger placement, and eye strain, especially during extended use of VR devices. By applying ergonomic principles, designers can create more comfortable and intuitive VR interfaces that reduce discomfort and physical strain on the user. In designing for VR, interactive VR designer Alger, M. [46] identified three main concepts: the content zone, the content size and the user presence and comfort.

Figure 3-30: The VR content zone concept of Mike Alger.



The content zone refers to the designated space in a virtual reality environment where users can interact with digital content such as 3D models, animations, videos, and audio. As the primary stage of the VR experience, its design and layout play a critical role in enhancing the overall user experience. The content zone typically serves as the central focus of attention in VR, often surrounded by navigation interfaces and other visual cues that aid users in navigating their virtual environment. The physical orientation of the user, whether standing or sitting, and their range of movements, influence content placement. Alger's diagram, shown in Figure 3-30, which incorporates comfort areas, takes into account the limitations of neck and eye movements to determine the available areas for content placement.

Mike Alger recommends avoiding persistent user interfaces within a 0.5m radius of the user as objects appear too close to focus on. Instead, the No-No zone is ideal for gestures or interactions that reveal settings or menu UIs as needed. On the other hand, anything beyond 20m loses depth perception significantly. Therefore, the distance between 0.5m to 20m, known as the Goldilocks zone, is the most suitable range for displaying content comfortably and meaningfully. However, screen-based VR displays have technological limitations that cause the eyes to focus only up to 2m, so placing content between 2-10m feels more natural and comfortable.
Alger defines three rectangular guides called:

- The **main content zone** is the most visible and comfortable, where viewers easily see content.
- The **peripheral zone** may cause strain and should not contain important content.
- The **curiosity zone** requires viewers to turn their bodies towards the content, indicating curiosity.

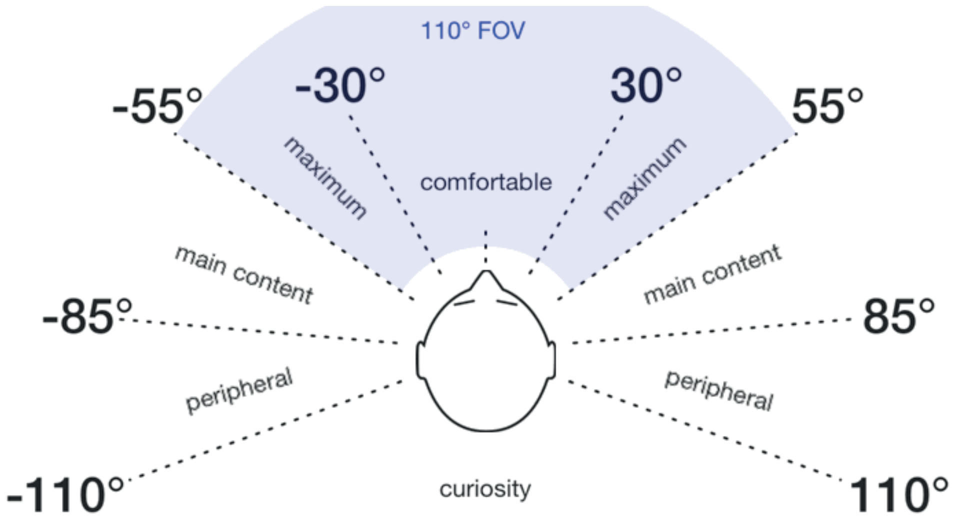


Figure 3-31: Alger's zone definitions using a 110° FOV horizontal and vertical.

When using modern HMDs with a 110° field of view, Mike Alger's approach to content placement in VR can be applied, which main information are synthesised in Figures 3-31 and 3-32. The Main Content zone should be positioned at 85° to each side, 75° up, and 67° down, while the Peripheral zone extends to 110° on either side and beyond 90° both up and down. Any content outside of the 110° range on either side and behind the viewer is considered the Curiosity zone. It's important to note that any content located in the peripheral zones is only detectable by our peripheral vision, unless we turn our heads. Therefore, important content is not suitable for placement in these zones. As the name suggests, any content placed in the Curiosity zone requires us to physically turn our bodies towards it, which implies interest or curiosity. It's worth noting that the placement of content may also be influenced by the technical constraints of screen-based VR displays, which may require content to be placed between 2-10m to feel most natural and comfortable for users.

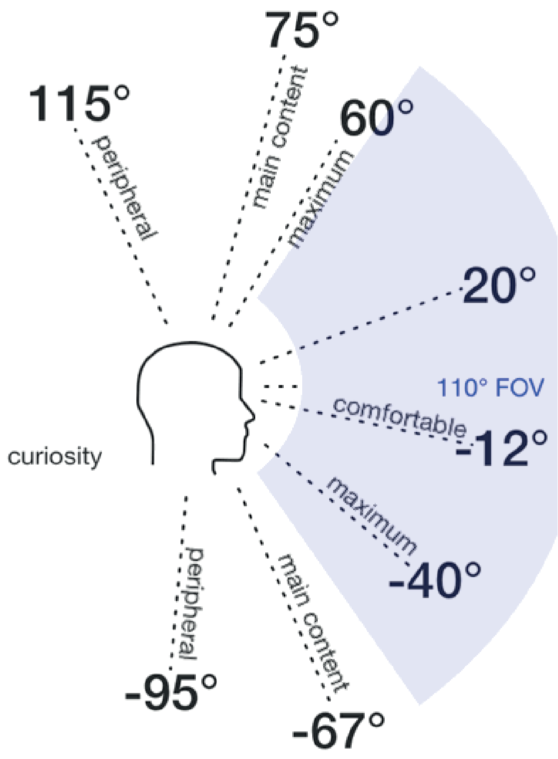


Figure 3-31: Alger's zone definitions using a 110° FOV horizontal and vertical.

Regarding the content size, the goal is to consider the user's perspective and ensure that the content is displayed consistently across different screen sizes and distances. To achieve this, Google [47] introduced a useful element called the distance-independent millimeter (DMM) into their design approach. The DMM is an angular unit of measurement that normalizes virtual screen space by defining 1 dmm as 1 mm at a distance of one meter, as shown in Figure 3-32 and 3-33. By using DMM, designers can ensure that their virtual reality content remains uniform and consistent regardless of the user's distance or the virtual screen size. This makes it easier to create immersive experiences that feel natural and intuitive to users.

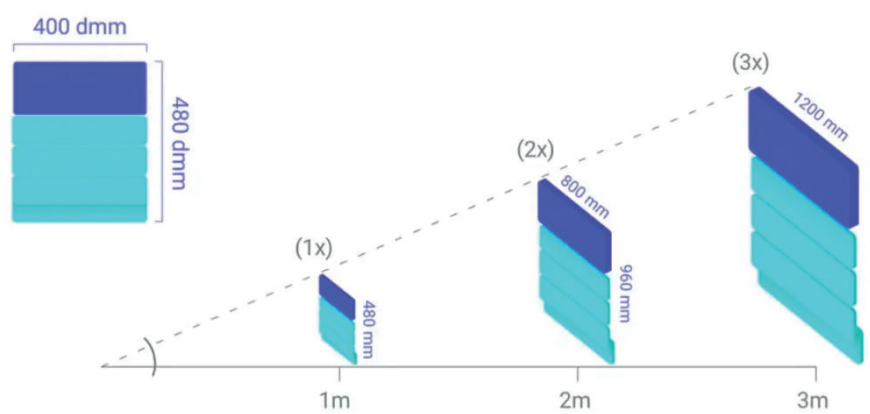


Figure 3-32: How DMM work.

Figure 3-33: 1 DMM.

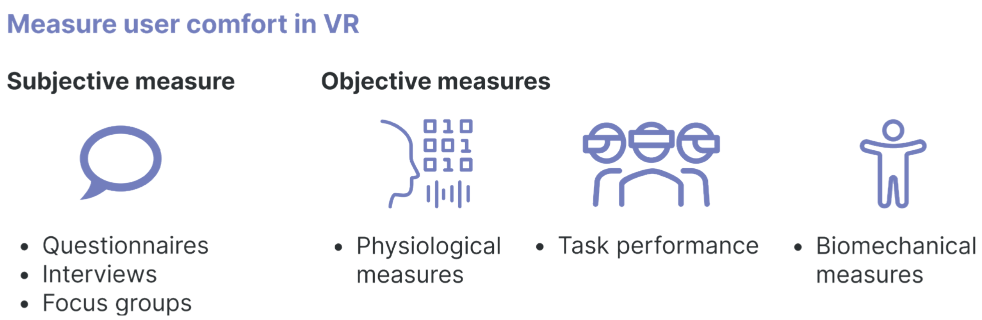
The aim of Google is to maintain content consistency while accommodating varying distances. However, when the distance between the user and the display changes, there can be a discrepancy between screen-space and world-space coordinates. For instance, at a distance of 2 meters, world-space coordinates double, which results in a 2x increase in screen size. As a result, Google can establish a standardised text and stroke size, providing with DMM a uniform measure for screen content
The study of these parameters allows designers to leverage depth and affordance. Depth can be used to differentiate between elements and establish a hierarchy within the content on the screen. Interfaces can be designed as flat, curved, folded, or detached, and the shape of the outline provides clues as to how the screen will interact with the user.

The user presence and comfort refers the level of physical and psychological comfort that a user experiences while interacting with an immersive virtual environment. Factors such as motion sickness, eyestrain, and disorientation can affect the user's comfort, making it crucial to design VR environments that are optimized for comfort, while also ensuring a balance between content size and the user's sense of presence and physical well-being. In order to prevent motion sickness, it is necessary to maintain a stable frame rate of at least 60 fps and a refresh rate of at least 60hz in VR technology. Additionally, enhancing the sense of presence with appropriate sounds and music is also important. Another factor to consider is the user's orientation in an unfamiliar VR environment. It can take around 10 seconds for users to orient themselves, and the position and arrangement of virtual objects can help provide context and shape the user's understanding of the virtual world and situation. If the initial positioning is unclear, it may be necessary to provide active guidance through text, sounds, voices, or guide arrows to provide context. However, these methods must be well thought out and planned systematically to avoid breaking the user's immersion and comfort state. Other important design elements to consider include conforming to the full scale of the world, creating a perception of being on the ground, and avoiding abrupt movements that can frighten or make the user feel ill. The camera should move at a constant speed, and objects should not appear to be coming towards the user too quickly. These recommendations can help create a more comfortable and immersive VR experience.

To ensure a comfortable experience, designers need to optimise the VR environment to prevent motion sickness, eye fatigue and disorientation. This includes maintaining a stable frame rate, enhancing presence with sound, guiding orientation, and avoiding abrupt movements.

Methods to evaluate and measure the user comfort in a virtual environment involves the combination of quantitative and qualitative methods [48].

Figure 3-36: Methods to measure user comfort in VR.



Subjective methods include:

- **Questionnaires**, asking users to rate their level of comfort on a Likert scale, or asking open-ended questions about their experience in the virtual environment.
- **Interviews,** conducting one-on-one interviews with users to get more in-depth information about their experience and opinions.
- **Focus groups,** gathering a group of users together to discuss their experiences in the virtual environment and share their opinions with each other.

Objective methods include:

- **Physiological measures**, such as heart rate variability, skin conductance, and electroencephalography (EEG).
- **Task performance**, assessing how well users are able to complete tasks in the virtual environment.
- **Biomechanical measures**, assessing user posture, muscle activity, and range of motion using motion capture technologies.

Both objective and qualitative methods can be used together to provide a more comprehensive evaluation of user comfort in virtual environments.

Usability

Usability, as defined by the ISO 9241 standard of 1998 [49], refers to the ability of a product to be used by specific users to achieve specific goals with effectiveness, efficiency, and satisfaction within a particular context of use. This definition implies that usability is not solely about ease of use, but also involves the ease of learning to interact with the product and experiencing satisfaction while doing so. According to prominent usability experts such as Nielsen, Krug, and Norman [17, 18, 50], usability is a quality attribute that assesses the ease of use of user interfaces and the quality of interaction between users and the product. Nielsen defines usability as comprising five elements: learnability, efficiency, memorability, errors, and satisfaction. These elements refer to how easy it is for users to accomplish basic tasks the first time they use the design, how quickly they can perform tasks once they have learned the design, how easily they can reestablish proficiency after a period of not using the design, how many errors they make and how easily they can recover from them, and how pleasurable it is to use the design. Heuristic evaluation and usability testing are methods for evaluating the effectiveness of a product by testing it with potential users. These methods provide direct feedback on how users interact with the system, and the usability of the design is measured based on the performance of the testers. The primary goal of these methods is to capture metrics and quantitative data on how users interact with the product, rather than subjective opinions on the quality of the design. Usability metrics are the most commonly used measures in heuristic evaluation and usability testing, and they can be classified

Usability is the measure of a product's ability to be used effectively, efficiently, and satisfactorily by specific users in a particular context. It goes beyond ease of use and includes factors such as ease of learning and satisfaction. Heuristic evaluation and usability testing are methods to measure the quality of user interface and interaction.

into three categories according to Kamińska, Zwoliński and Laska-Leśniewicz [51]. The first category is user behaviour, which is typically observed during testing. It includes measures such as task completion time, error rates, and the number of clicks required to complete a task. The second category is user thoughts and opinions, which are typically collected through surveys or interviews. This category includes measures such as user satisfaction, ease of use, and overall user experience. The third category is captured data, which includes data collected from tools such as click paths, eye-tracking heat-maps, and other analytical tools.

Figure 3-37: Common usability metrics divided in three categories [51].

Heuristic evaluation and usability testing are powerful methods for evaluating the usability and effectiveness of a product, and the metrics collected provide valuable insights into how users interact with the product. By analysing these metrics, designers can identify areas for improvement and make changes to the design to improve its usability and overall user experience. Overall, there are many methods for measuring and evaluating usability in a virtual environment, and the main methods are divided in Figure 3-38 into subjective and objective methods.

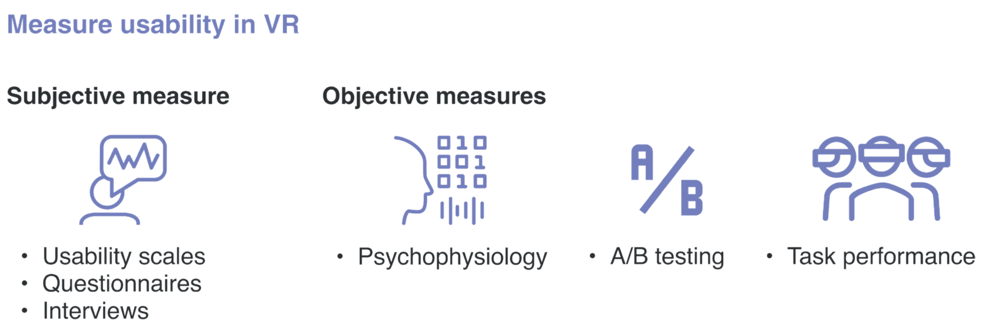


Figure 3-38: Usability measurement methods in VR.

Subjective methods include:
- **Questionnaires and interviews** that gather users' impressions and perceived feelings about the VR experience [52].
- **Scales** such as the SUS (System Usability Scale) [53].

Objective methods, on the other hand, include:
- **A/B, A/B/n or multi-variant tests.**
- **Physiological indicators** such as heart rate, galvanic skin response and muscle response.
- **Observation** of user behaviour [54].
- Record **biomedical signals** such as EEG signals, motion and eye tracking.

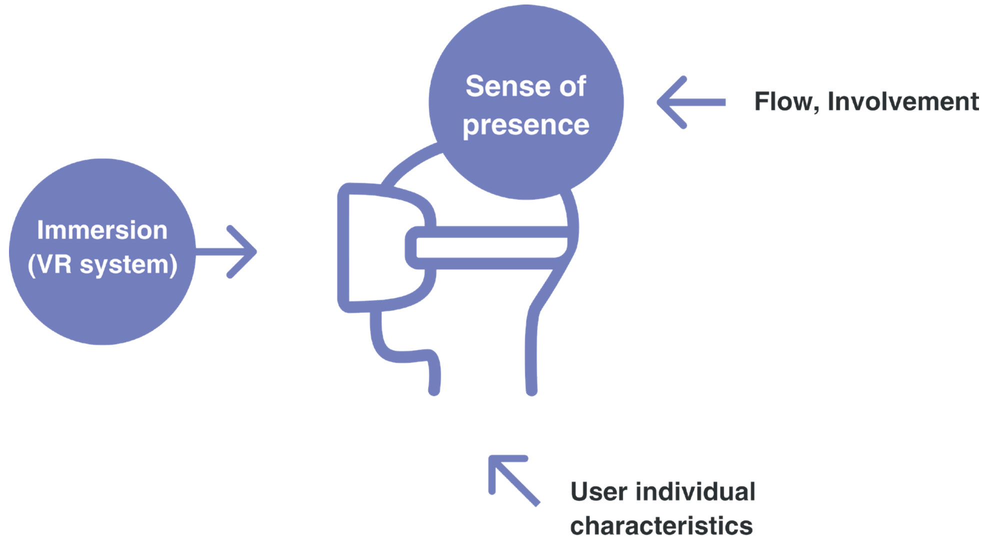
While objective metrics can provide solid and measurable evidence, subjective methods such as questionnaires are the most popular tool for data acquisition. This is because objective methods can suffer from logistical problems such as monitoring and recording equipment. Therefore, it is important to use both objective and subjective methods in a complementary manner, with well-formulated questionnaires collecting user feedback and objective analysis confirming the evaluation. This approach can provide a more comprehensive and accurate evaluation of user comfort in virtual environments.

Perception and cognition

Creating an immersive experience involves creating a computer-generated environment, either a replica of reality or a completely imaginary world, that enables the user to feel as if they are in a different location. To achieve this "being there" experience, it is crucial to understand the key concepts and elements involved in creating a successful and immersive VR experience. There are several related but distinct concepts in the field of VR, including involvement, immersion, flow, and presence. These concepts refer to different aspects of the user's experience of being in a virtual environment, as shown in Figure 3-39, and they should not be equated with each other. For instance, presence can be achieved without being fully immersed in the virtual world, such as when carrying out a repetitive task in a virtual simulation [55]. Understanding the different concepts involved in VR is essential for designers and developers to create engaging and effective VR experiences. By focusing on these key elements, they can design VR applications that meet user needs and preferences while also considering the limitations and challenges of the technology.

- **Immersion** refers to the feeling of being fully engaged in the experience
- **Presence** refers to the sense of "being there" in the virtual environment.
- **Flow** refers to the state of complete focus and involvement in a task within the VR environment.

Figure 3-39: Perception and immersion.



Immersion

Immersion in virtual reality refers to the objective level of sensory fidelity and the degree to which the user feels physically present in the virtual environment. It depends on various factors such as the quality of the display and audio, interactivity, agency, realism, and immersion level in the virtual environment. The quality of these factors can make the environment more realistic, and users are more likely to experience a sense of presence. [56, 57]. However, immersion alone is not enough to create a compelling VR experience. The human mind's interpretation and perception of the stimuli are also crucial in determining how the user experiences immersion, which is known as presence.

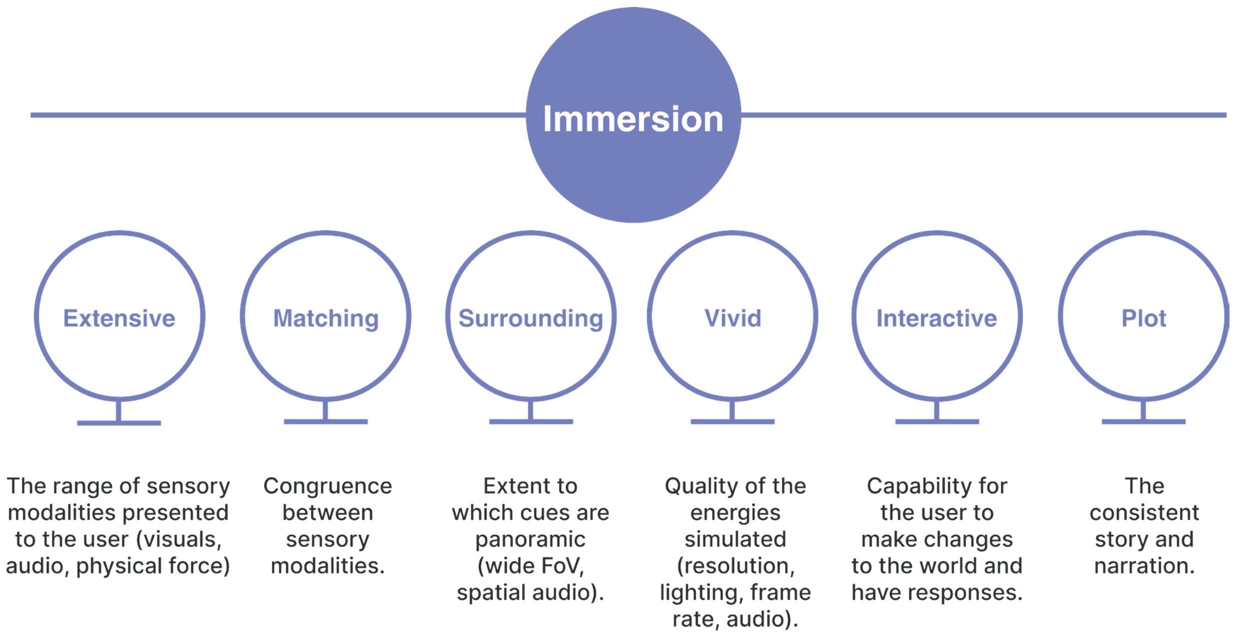
Presence

Presence refers to the subjective feeling of being in the virtual environment and is influenced by factors such as the user's expectations, familiarity with the environment, and emotional engagement [58]. Presence, in contrast to immersion, is a subjective state of consciousness that describes the feeling of "being there" in the virtual environment while experiencing a VR system. It is a perceptual illusion where the user's perceptual system identifies the objects and events in the virtual environment, and the brain-body system automatically responds to the changes in the environment, while the cognitive system slowly concludes that the experience is an illusion [59]. Presence is a complex construct that can be influenced by various factors such as visual, auditory, haptic, and proprioceptive cues, as well as the user's cognitive and emotional state. Presence is often described as a multidimensional construct

that encompasses the user's sense of presence in the virtual environment, sense of self in the virtual environment, and sense of agency. The level of presence experienced by a user in a virtual environment is influenced by several factors, such as how accurately the virtual environment can replicate real-world physics and the user's sense of self within it. A higher level of presence can make the experience more engaging and realistic, while a lower level of presence can cause the user to feel disengaged and disconnected. This is because presence is closely linked to the user's ability to suspend disbelief and fully immerse themselves in the virtual environment [60]. However, a break-in presence can occur when the illusion of being in a virtual environment is disrupted, causing the user to become aware of their real-world surroundings and lose the sense of immersion. This can greatly diminish the effectiveness of the VR experience, and measures should be taken to minimise these disruptions. Some common examples of factors that can cause a break-in presence include someone speaking from the real world, real-world sounds like a phone ringing, technological limitations, hardware issues, or user discomfort. Different researchers have categorised presence into various forms depending on the illusion created. For example, some types of presence include an illusion of being in a stable spatial place [61], self-embodiment [62], physical interaction [63], and social communication [64].

Presence is the feeling of being in a virtual environment, influenced by cues and the user's state. It is a multidimensional construct comprising presence, self and agency. Factors that interfere with it cause disengagement.

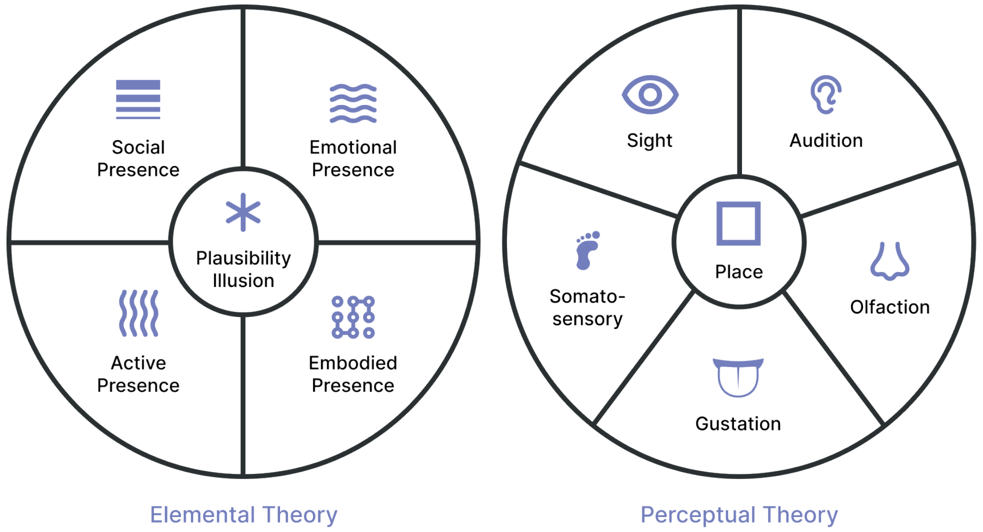
Figure 3-40: Framework for presence factors (adapted from Jerald, J. [59]).



The two models that summarise different theories of presence are the "Elemental theory of presence" by Bye K. and the "Perceptual theory of presence"[65], shown in Figure 3-41, inspired by the work of Slater J. The Elemental theory of presence posits that presence is a multi-component construct composed of four elements: sensory fidelity, spatial presence, involvement, and realness. The theory highlights the importance of the richness and realism of sensory inputs in creating a sense of presence. It also recognizes the role of social and temporal factors, such as the feeling of being with others and the sense of time passing in the virtual environment, in enhancing the sense of presence. In contrast, the Perceptual theory of presence focuses on the psychological processes underlying the perception of presence in a virtual environment. It suggests that presence is a perceptual phenomenon that results from the brain's interpretation of sensory inputs, including visual, auditory, haptic, and vestibular stimuli. The theory asserts that presence is achieved when the virtual environment can create a convincing illusion of being in an actual physical space by providing cues similar to those experienced in the real world.

The elemental theory focuses on sensory inputs and factors such as social and temporal, while perceptual theory emphasizes the brain's interpretation of sensory cues.

Figure 3-41: Bye's 'Elemental Theory of Presence and the Perceptual Theory of Presence [65].



Both theories highlight the importance of sensory inputs in creating a sense of presence, but they differ in their emphasis on the underlying psychological processes. The Elemental theory emphasises the role of social and temporal factors, while the Perceptual theory focuses on the brain's interpretation of sensory inputs.

Flow

Flow, also referred to as being "in the zone," is a term used to describe a mental state in which there is an appropriate match between someone's

skills and the challenge presented to them, resulting in an experience of intense involvement. Flow is a psychological state characterised by intense focus, motivation, and enjoyment of an activity [66]. In the context of VR, flow can be achieved when the challenge level presented to the user matches their skill level, leading to complete immersion in the virtual environment, as shown in the theory model by Csikszentmihalyi in Figure 3-42 . There is a growing body of research on how to induce flow in VR environments. One study found that affordances, or the properties of objects and the environment that make them usable for a specific task, can be used to induce a flow state in VR [67]. For example, manipulating the size and speed of obstacles in a VR game can match the player's skill level and lead to a flow state. Another study has shown that presence can enhance flow in VR [68]. High visual and auditory accuracy and a lack of delay in the VR system can boost presence and increase the likelihood of achieving a flow state. Thus, achieving a state of flow in VR is not only about the match between the user's skill level and the challenge level presented but also about creating an immersive and realistic VR environment that allows the user to feel fully present and engaged.

The elemental theory focuses on sensory inputs and factors such as social and temporal, while perceptual theory emphasizes the brain's interpretation of sensory cues.

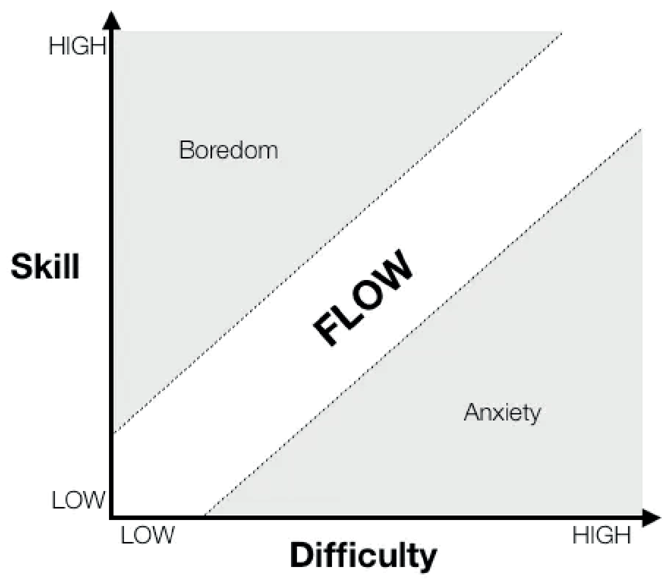


Figure 3-42: Csikszentmihalyi's cognitive flow theory [66].

There are several methodologies to evaluate perception and cognition in VR and as immersion is more objective and presence more subjective, research is exploring both subjective and objective measurements.

Figure 3-43: Methods to assess perception and cognition in VR.

Measure perception and cognition in VR

Subjective measure | **Objective measures**

- Questionnaires
- Interviews
- Psychophysiology
- Behavioural
- Performance

Subjective measurements include **questionnaires and surveys** in which participants can be asked about their experience and perceptions in VR to gather subjective data. Tools to measure are:

- PQ (Performance Questionnaire), the most used questionnaire to measure involvement and immersion [69, 70].
- IPQ (Item Performance Questionnaire) to assess presence and engagement [71, 72].
- ITQ (Igroup Presence Questionnaire) to assess the presence and to determine characteristics of subjects, which potentially cause biases and affect subsequent judgments of presence [73].
- IEQ (Immersive Experience Questionnaire) to access cognitive involvement, absorption, and flow [74, 75].
- MRJPQ (Modified Reality Judgment and Presence Questionnaire) to measure the presence and the emotional impact of the simulated scenario [76].
- The GEQ (Game Experience Questionnaire) is designed to measure the user's subjective experience of playing video games [77].
- The E2I emphasised the role that enjoyment has in the presence [78].
- Flow4D16 for measuring the state of the flow [79].
- VRLEQ (VR Locomotion Experience Questionnaire) to measure subjective experience of presence, immersion, and flow in virtual reality [80].

Objective measurements include:

- Psychophysiology measures, with techniques such as EEG, eye tracking, and galvanic skin response that can be used to measure physiological responses to VR stimuli, giving insight into perception and cognition.
- Behavioural measures, in which tasks and activities can be designed to measure specific perceptual and cognitive abilities, such as attention, memory, spatial awareness, and reaction time.
- Performance measures, that means objective measures like accuracy, response time, and completion time can be used to assess performance in specific tasks.

Workload

The processing, retention, decision-making, and task performance abilities of humans are limited. Human factors and ergonomics utilize the concept of workload to represent the mental cost and effort required for tasks, encompassing physical, mental, and emotional demands [81, 82]. The workload is also defined as the proportion of information processing capability required for task execution. Overloading may lead to decreased task speed and errors, while underloading can result in boredom, loss of situational awareness, and reduced alertness. Mental workload encompasses various processes, including neurophysiological, perceptual, and cognitive processes and is influenced by multiple factors, such as the complexity and number of tasks, time pressure, workload management strategies, physical and mental demands, availability of resources, as well as individual capabilities and characteristics, such as age and experience, motivation, and physical and emotional states affecting task performance strategies. There are several theories related to the concept of mental workload and ongoing research, synthesised in the diagram in Figure 3-44, aims to identify an optimal definition [83].

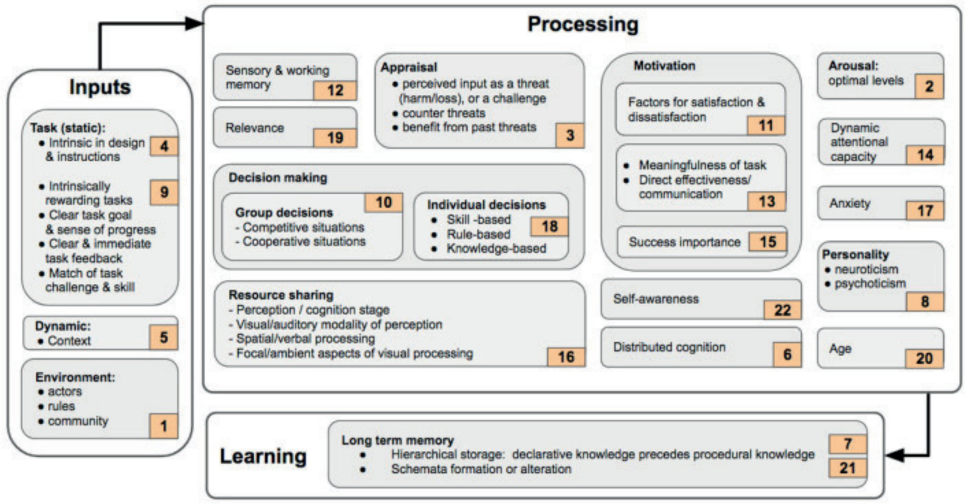


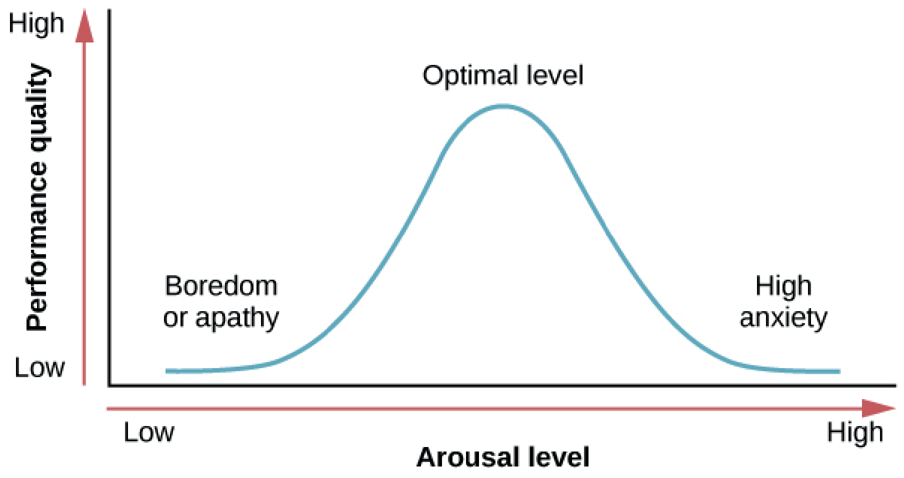
Figure 3-44: Theories linked to mental workload organised as a framework [83].

In this thesis, various theories will be explored to gain a better understanding of the relationship between mental workload and task performance. These theories offer different perspectives on this crucial link and can provide valuable insights into how tasks and environments can be designed to reduce mental workload and improve performance. Among the main theories that will be explored in this thesis are the Arousal Theory, the Cognitive Load Theory (CTL) and the Multiple Resource Theory (MRT).

The **Arousal Theory** suggests that optimal task performance is achieved when individuals experience a moderate level of arousal. This theory proposes that both low and high levels of arousal can negatively impact performance, with low arousal resulting in reduced motivation and attention, and high arousal leading to anxiety and stress.According to the Arousal Theory, mental workload and task performance are closely linked to the level of arousal or activation of the central nervous system. Arousal is a physiological state that reflects the level of activity in both the brain and body [84]. For optimal performance, an individual's arousal needs to be at a moderate level, not too low and not too high. When engaged in a task, the level of arousal increases as the individual's brain and body become more active in response to the task's demands. This increased arousal is thought to be associated with higher mental workload, as the individual must allocate more mental resources to perform the task effectively. Inadequate levels of arousal can lead to poor performance due to a lack of motivation or attention. Too little arousal can result in sleepiness or fatigue. On the other hand, excessive arousal levels can cause stress and anxiety [85]. Therefore, maintaining an optimal level of arousal is crucial to achieving peak performance in tasks. Understanding the relationship between arousal and mental workload can help design tasks and environments that promote optimal arousal levels and improve overall performance.

The Arousal Theory suggests that moderate arousal levels are optimal for task performance. It affects behaviour and performance; the optimal level varies and can be regulated for better outcomes.

Figure 3-45: Optimal arousal - Yerkes & Dodson model [85].



The **CTL** asserts that working memory is limited, and therefore, tasks that require a higher cognitive load can lead to mental overload and decreased performance. It provides a theoretical framework for understanding how the human mind processes information and how this affects learning [86]. It suggests that the amount of mental capacity, or working memory, available for processing information is limited and can be influenced by various factors, including the nature of the task and the design of instructional materials. The theory outlines three forms of cognitive load [87], shown in Figure 3-46. The first is intrinsic cognitive load, which is the inherent complexity of the material or task itself and cannot be altered or reduced. The second is extraneous cognitive load, which is caused by the way instructional materials are presented, such as poor design or irrelevant information. This type of load can be reduced through good instructional design. Finally, there is germane cognitive load, which is associated with learning and constructing mental representations and is necessary for effective learning. This type of load can be increased through well-designed instruction. By understanding the different forms of cognitive load, instructional designers can create materials that maximise germane cognitive load while minimising extraneous cognitive load. This approach can lead to more effective learning and improved performance on tasks. According to the CLT theory, instructional materials should be designed to minimise extraneous cognitive load, or the mental effort required to process irrelevant or redundant information, while maximising intrinsic cognitive load, or the mental effort required to process essential information. This can be achieved through various techniques such as presenting information clearly and concisely, using visual aids, and breaking down complex information into smaller, more manageable pieces.

The CTL suggests that working memory is limited and explains how tasks with high cognitive load can lead to decreased performance.

The CTL outlines three forms of cognitive load: intrinsic, extraneous, and germane. Instructional design can maximise learning and improve task performance by reducing extraneous load and increasing germane load.

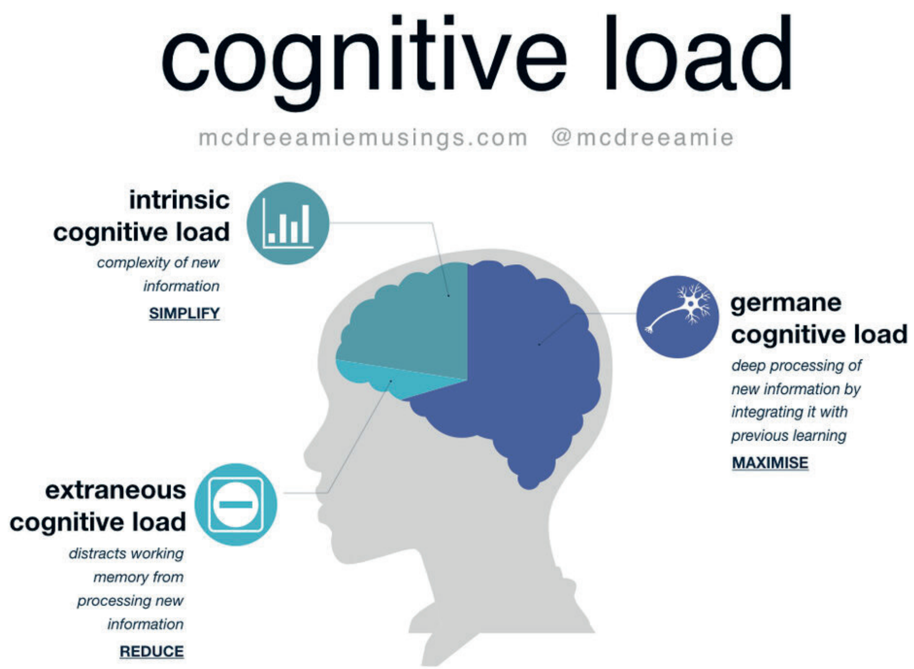


Figure 3-46: Types of cognitive load [87].

The aim of CLT is to support effective learning by reducing the mental workload associated with processing information. By minimising extraneous cognitive load, learners can focus their limited mental resources on the most important information, which maximises their ability to learn and retain information. Effective instructional design can lead to improved performance on tasks and better overall learning outcomes.

The last theory explored is the **MRT**, which explains how the limited capacity of the human working memory affects the processing of information and performance on cognitive tasks [88]. According to MRT, different types of mental resources are used for different types of tasks, and the amount of mental workload depends on the demands of the task and the availability of mental resources. MRT suggests that the performance on a particular task can be affected by the demands of other tasks that compete for the same mental resources. For instance, a high workload in one task can reduce the availability of resources for another task, leading to decreased performance. This theory provides a framework [89], shown in Figure 3-47, for understanding the trade-offs between different types of tasks and their impact on performance.

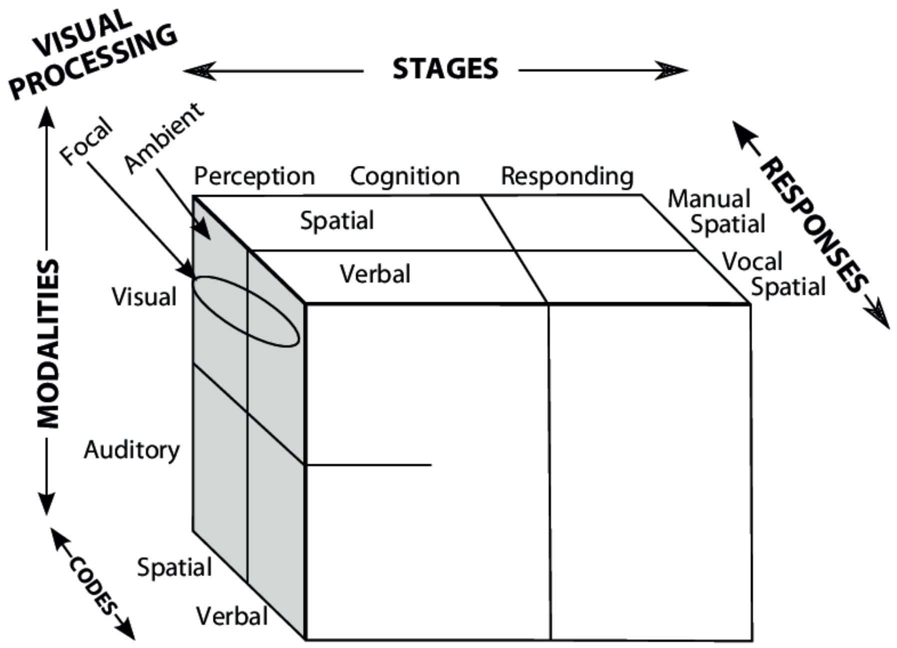


Figure 3-47: Dimensional structure of human processing resources model by Wickens [97].

This knowledge can help in designing systems and work environments that minimise the negative effects of workload and optimise overall performance. By identifying the resources required for different tasks, it is possible to allocate resources in a way that maximises performance on all tasks.

By examining these theories and understanding their implications for task design and performance, researchers and practitioners can work towards creating more efficient and effective environments and improving individuals' cognitive abilities. When evaluating mental workload in both real and virtual environments, two main types of measurements are commonly used, shown in Figure 3-48: subjective and objective methods [90].

Measure workload in VR

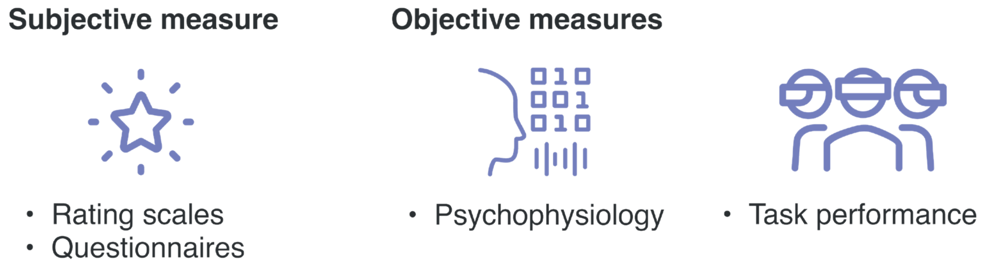


Figure 3-48: Methods to assess workload in VR.

Subjective measurement for evaluating workload in a VR experience include:

- **Self-report** that involves a participant providing qualitative and/or quantitative reports concerning the personal experience while performing the tasks. Can be asked to answer a pre or post-task questionnaire.
- **Ratings and scales**, where participants are asked to rate their perceived workload while completing tasks in VR, similar to traditional subjective ratings. A well trained observer can make judgments of the participant's workload based on observation of behaviour and physiological responses. The most used tools are NASA-Task Load Index (NASA-TLX) [91], Workload Profile, Subjective Workload Assessment Technique (SWAT) and Rating Scale Mental Effort. All these tools consist of a set of weighted rating scales that assess different dimensions of workload including mental demand, physical demand, temporal demand, performance, effort, and frustration [92].

Objective measurements for evaluating workload in a VR experience include:

- **Physiological and neurophysiological assessment** includes electro cardiac and cardiovascular measures, respiration measures, ocular measures, neuroendocrine measures and speech measures [93].
- **Performance assessment**, that involves measuring task performance on one or more relevant tasks, such as reaction time, accuracy, or task completion time.

Both subjective and objective methods can provide valuable insights into workload in a VR experience. Subjective methods offer the advantage of capturing the user's perspective, providing rich qualitative data about their experience, and highlighting areas that require improvement. Objective methods, on the other hand, offer more precise and quantitative data that can be used to measure the effectiveness of specific design interventions or to compare different VR experiences. A combination of both methods is often recommended for a comprehensive evaluation of workload in a VR experience.

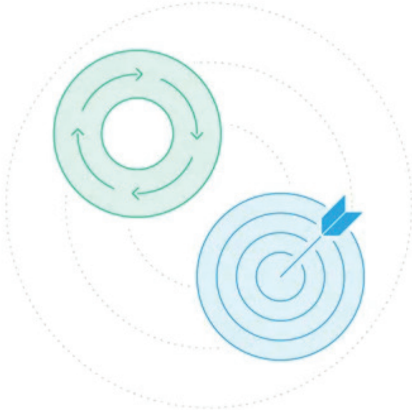
Accessibility and inclusivity

Figure 3-49: Accessibility and inclusivity.

Accessibility focuses on outcome-based qualities or attributes.

/

Inclusivity is a process-based methodology.



A core component of human factors is accessibility that, in this thesis, comprehends inclusion, diversity and equity. Accessibility involves designing digital products and websites in accordance with accessibility guidelines to ensure that people with disabilities can access them effectively. Inclusivity, on the other hand, is a process-driven methodology that focuses on creating products that are user-friendly for everyone [94]. A meeting point are approaches such as Design for All [95] and Universal Design [96] where products are designed to be usable by all people, to the greatest extent possible, without the need for specialised adaptation. The aim is to enter a new era of information and communication technology where services and devices can be tailored to meet the needs of every user, rather than just the majority.

Figure 3-50: Experiments in accessible VR development.

The field of virtual reality is constantly evolving, and efforts are being made to make it accessible to everyone. However, there are still significant barriers that prevent people with disabilities from accessing VR experiences. These barriers include visual, auditory, cognitive, and motor limitations that make it difficult for some users to interact with virtual environments effectively. Many VR experiences rely heavily on the use of the head, hands, and arms, requiring upper body movements or even standing up, which can be challenging for people with physical disabilities. Moreover, in many games and experiences, there are no alternative input methods available besides using a controller, which may be difficult for users with certain disabilities.

To address these challenges, some VR companies have developed their own accessibility guidelines [97], including:

- **XR Accessibility User Requirements** [98] published by the Accessible Platform Architectures (APA) Working Group of the World Wide Web Consortium (W3C).
- **Oculus VRCs Accessibility Requirements** [99], the set of accessibility requirements that developers must or should follow to publish their apps on Oculus devices released from Oculus.

These guidelines aim to promote inclusive design practices that consider the needs of all users, including those with disabilities. By incorporating these accessibility guidelines, summirized in Figure 3-51, VR experiences can become more accessible and inclusive, providing equal opportunities for everyone to experience the benefits of this exciting technology.

Fundamental is assessing the accessibility and inclusivity of virtual environments to ensure that the experiences are accessible to all users. There are several methods and tools that can be used to measure and assess accessibility and inclusivity for virtual environments, these are summarised in Figure 3-52.

Measure accessibility and inclusivity in VR

Figure 3-52: Methods to assess accessibility and inclusivity in VR.

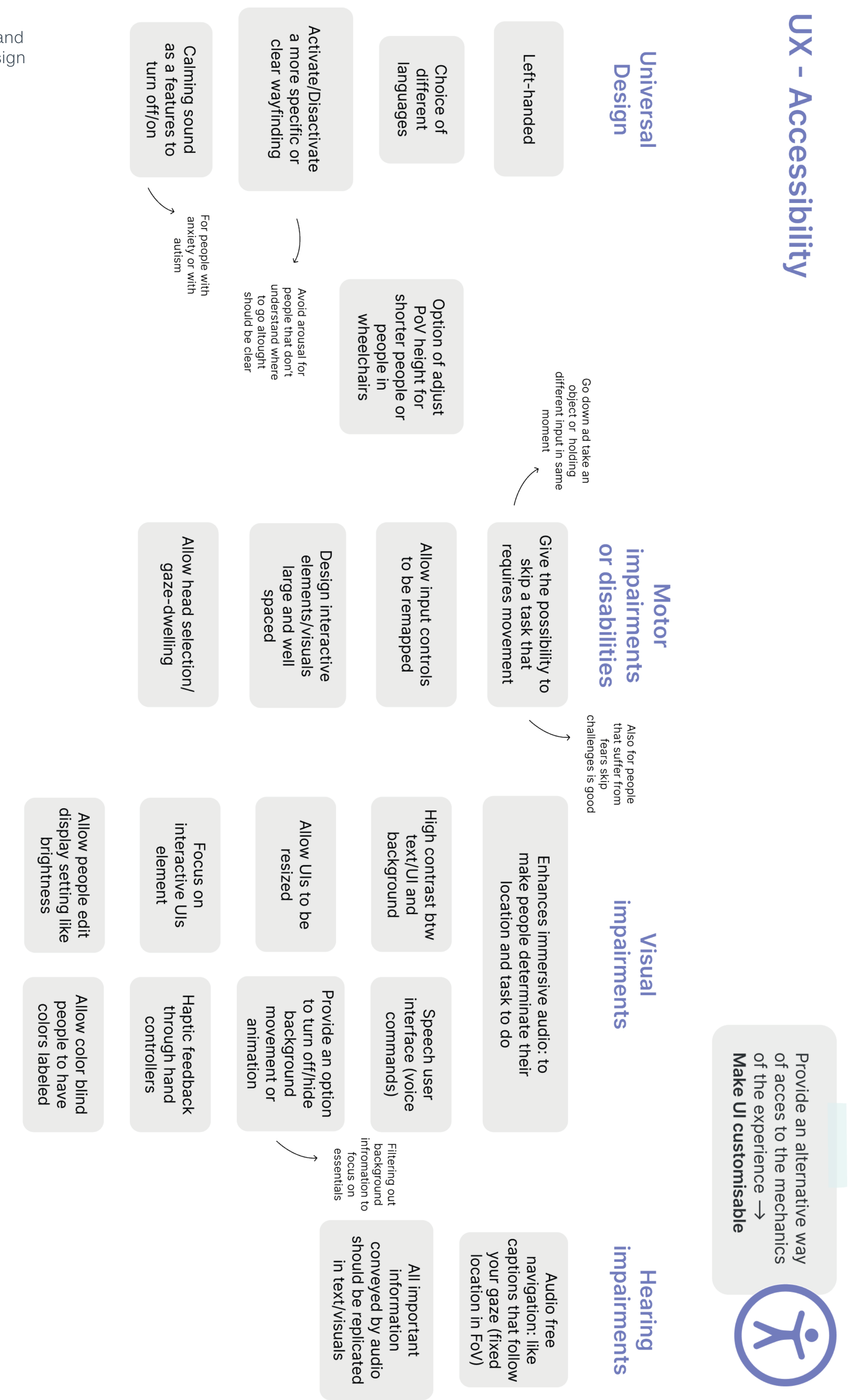
Subjective measure

- User testing with people who have a range of abilities and disabilities

Objective measures

- Use of automated testing tools
- Plugins, software

Figure 3-51: Accessibility and inclusivity design strategies.



Subjective methods involve **gathering feedback** from users with a range of abilities and disabilities to identify any barriers or challenges they may face when using the virtual environment. This can involve conducting **interviews** or **surveys**, or using **assistive technologies** to simulate different disabilities. Some examples of plugins and tools that can help with subjective testing include:

- Accessibility Testing Toolbar, a browser extension that provides a suite of tools for testing web content accessibility. It includes options for simulating different disabilities, such as colour blindness and screen readers.
- VoiceOver on Mac: This is a built-in screen reader for Mac computers that can be used to test the accessibility of web content and applications.
- NVDA: This is a free, open-source screen reader for Windows that can be used to test the accessibility of web content and applications.

Objective methods rely on **automated testing tools** to scan the virtual environment for accessibility issues and provide recommendations for improvement. These tools can detect issues such as missing alt text for images, insufficient colour contrast, or inaccessible navigation. Some examples of plugins and tools that can help with objective testing include:

- Accessibility Scanner for Unity, a plugin automatically scans Unity projects for accessibility issues and generates a report with suggested fixes.
- Accessibility Insights for Web, a browser extension that can help developers test web content for accessibility issues. It provides a suite of automated and manual tests to identify issues and generate reports.
- A-Frame Accessibility Checker, a tool checks A-Frame virtual environments for accessibility issues and provides recommendations for improvement.

Overall, both objective and subjective methods are important for measuring and assessing the accessibility and inclusivity of virtual environments. Developers can use a combination of automated testing tools and user feedback to ensure that their virtual environments are accessible to all users.

Physical safety

Physical safety in VR refers to the measures taken to prevent injury to users while they are immersed in a virtual environment. It involves taking measures to prevent users from getting injured while they are immersed in a virtual environment. The design of VR experiences must take into account the types of movements required by the experience. For instance, some experiences may require users to perform sudden, fast movements, while others may require more controlled, gentle movements. Designers have a responsibility to ensure that VR experiences are designed in a way that minimises the risk of injury and promotes safe movements [100]. This can be achieved by incorporating safety features into the VR experience, such as warning users about potentially hazardous movements or providing clear, concise instructions on how to perform movements safely. In addition, designers should consider the physical limitations of users, such as their age or physical ability, and ensure that the VR experience is suitable for all users. Overall, physical safety is a crucial aspect of designing VR experiences. It not only protects users from injury but also ensures that they can fully immerse themselves in the virtual environment without any fear or hesitation. By prioritising physical safety, designers can create VR experiences that are not only entertaining and engaging but also safe and inclusive for all users. There are several factors to consider in order to ensure physical safety in VR, including:

VR experiences should consider the types of movements required, physical limitations of users, and incorporate safety features.

- Space requirements, which means that the VR headset and other equipment should be used in a safe and spacious environment, free of tripping hazards and other obstacles.
- Movement tracking to track the user's movements accurately, to avoid collisions with objects in the real world and minimise the risk of injury.
- Wearable design that should be designed for comfort and safety, with adjustable straps and padding to avoid pressure points and discomfort.
- Environmental design, so the virtual environments should be designed to prevent users from accidentally walking into walls, furniture, or other objects in the real world.
- Emergency stop mechanism, which means an emergency stop mechanism, such as a button or gesture, that allows users to quickly exit the virtual environment in case of an emergency.

By prioritizing physical safety, designers can create VR experiences that are entertaining, engaging, and inclusive for all.

By considering these and other physical safety factors, VR companies can ensure that users have a safe and enjoyable experience while using their products. As the other factors, there are various methods to measure and assess physical safety, which can be broadly classified into two categories: objective and subjective methods, as summarised in Figure 3-53.

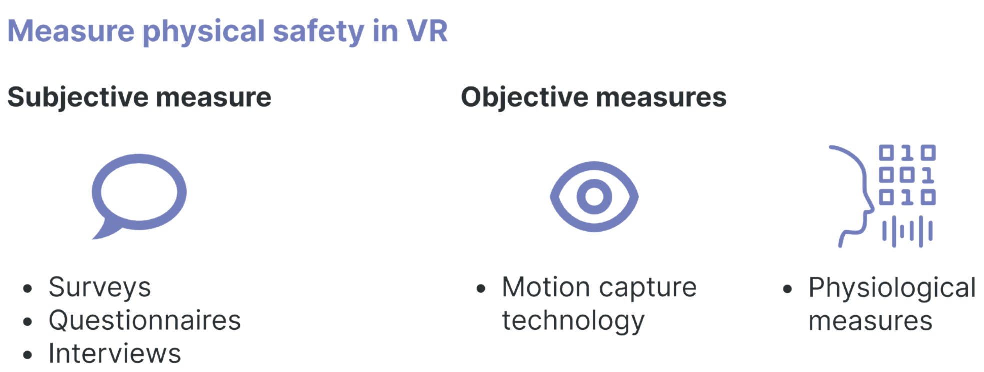


Figure 3-53: Methods to assess accessibility and inclusivity in VR.

Subjective methods involve:

- **Surveys**, **questionnaires**, or **interviews** to collect qualitative data on users' perceptions of the physical safety of the VR experience. These methods typically involve asking users to provide feedback on the comfort, safety, and overall experience of the VR environment.
- **Focus groups** or **usability testing** to gather feedback on specific aspects of the VR experience, such as the effectiveness of safety warnings or the clarity of instructions on how to perform movements safely.

Objective methods involve:

- **Motion capture technology**, as a way of collecting quantitative data in which it is possible to track the movements of users and identify any movements that could result in injury, such as the number of collisions, falls, or other physical incidents that occur during the experience.
- **Physiological measurements** through sensors or wearable devices that can measure the physical responses of users, such as changes in heart rate, breathing, or temperature.

Overall, both objective and subjective methods are important in measuring and assessing physical safety in VR. While objective methods can provide valuable data on the physical aspects of the experience, subjective methods can provide insights into how users perceive the safety of the environment and the effectiveness of safety measures put in place by designers.

Diegesis in VR

This subchapter is dedicated to illustrating the characteristics of diegesis applied to vr technology.

Diegesis

Diegesis is a term that originated from the Greek word "diegesis," which means "narration" or "narrative". The concept of diegesis was explored by ancient Greek philosophers such as Aristotle and Plato and has now evolved into a useful tool for analysing media and measuring immersion in a particular work. In VR, diegesis refers to the narrative space within the virtual environment, including the events, characters, locations, and sounds that the user experiences. In fact, it refers to the internal narrative space of the virtual environment and is closely related to the concept of immersion, which refers to the degree to which a user feels transported into the virtual environment. By creating a coherent and believable narrative space, designers can increase the sense of presence and realism in the virtual environment [101]. Diegesis in VR can be affected by various factors, such as the quality of the visual and auditory design, the user's physical movements and interactions within the virtual environment, and the consistency of the narrative elements within the virtual world. In addition to visual design, sound design is also an essential aspect of diegesis in virtual reality. Diegetic sound refers to the sounds that originate within the virtual environment, such as character dialogue and environmental sounds. It can create an immersive soundscape that helps the user feel as if they are really a part of the storyworld. These sounds are part of the world, and they can include things like character dialogue, footsteps, and environmental sounds. Even if they are not visible on screen, they are understood by the audience to be part of the story's environment. There are two subcategories of diegetic sound: extra-diegetic and intra-diegetic [102].

Diegesis in VR refers to the narrative space and immersion within the virtual environment. It can be enhanced by visual and auditory design, user interaction, and consistency of narrative elements.

- **Extra-diegetic sound** is integrated into the game's visual elements but is not noticed by the game characters. Examples of extra-diegetic sound include score counts, health status bars, and alerts. Intra-diegetic sound is the same as diegetic sound, but it excludes non-diegetic visual interface elements.
- **Non-diegetic sound**, on the other hand, is sound that originates from outside of the scene, and it includes sounds that the characters in the story cannot hear. Examples of non-diegetic sound include the narrator's voice and the film score.

In conclusion, trans-diegetic sound describes any sound that moves between the diegetic and non-diegetic layers. An example of trans-diegetic sound would be a character whistling a tune that is gradually played by an orchestra or a narrator's voice fading into a song played by a band in a bar.Understanding the different types of sound in a virtual environment is important for creating an immersive experience for the user. By using diegetic sound effectively, designers can create a believable and cohesive virtual world that draws the user into the experience.

Experiments case studies and its influence in VR

To the purpose to investigate how the application of different levels of diegesis impacts on a virtual reality experience in the context of learning, several literary science-based experience and experiments were explored. The resources of the last five years have been taken into account, with similar technology to be used, such as HDMs. In general, according to various research studies [103, 104, 105], incorporating diegetic elements in VR can significantly enhance the immersion and engagement of users, making the virtual experience more realistic and believable. The inclusion of diegetic elements such as visuals and auditory cues has been found to increase student engagement in educational experiences [103].

Figure 3-54: diegetic UI mediated as an agent in an experiment study [103].

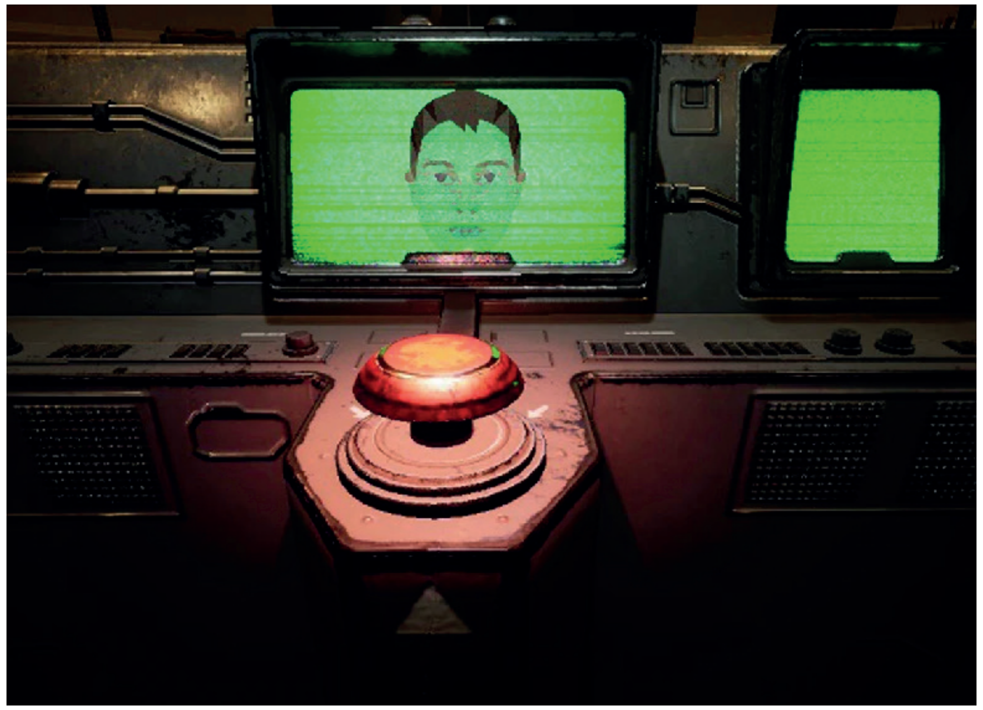


Figure 3-54: diegetic UI mediated as an agent in an experiment study [103].

However, some studies claim instead that there is no difference in impact in terms of immersion and engagement [106, 107]. Furthermore, the different studies have also suggested that non-diegetic interfaces may be more effective and user-friendly for users who are unfamiliar with the VR environment or performing tasks requiring precise input. It has been found that the level of diegesis can affect the user's performance and task completion, and a higher level of diegesis can enhance immersion and make the virtual experience feel more authentic. Overall, users tend to prefer diegetic interfaces as they make the virtual experience more meaningful and impactful. However, further research is needed to explore how diegetic elements can affect learning outcomes in VR. Thus, it is important to conduct additional studies to investigate the influence of diegetic interfaces on learning outcomes and determine the most effective design principles for creating educational VR experiences.

Diegetic and non-diegetic UI patterns in video games

Video game designers face the challenge of creating user interfaces that are both immersive and functional. The UI must not only complement the game's narrative but also provide the player with essential status and performance information. To achieve this, Fagerholt and Lorentzon [108] created a chart that categorises each UI element based on two variables: fiction and spatiality. Fiction refers to how closely the UI element is integrated into the game's narrative or diegesis. A highly fiction UI element would be one that is seamlessly integrated into the game's story, such as a compass that appears as a part of a character's clothing or a health meter that takes the form of a bracelet. Spatiality refers to the location of the UI element in the game's virtual space. A spatial UI element appears within the game's world and is usually associated with the game's fictional objects, while a non-spatial UI element is displayed outside the game's world, often as an overlay on top of the game's graphics. From this chart, we can see the distinction between 4 types of UI:

- **Non-diegetic** elements refer to game UI components that are not part of the game world and are only visible and audible to players in the real world. An example is traditional Heads-up Display (HUD) elements such as a life meter, that shows how much life a player has, a menu, to spin through resources or actions, or a level map.
- **Diegetic** are UI elements that provide the player hints without dissociating the player too much from the narrative. Diegetic components are part of the game world and visible and audible to the characters. These components give players the necessary information, in a minimalistic way, while keeping them immersed in the game's narrative. Examples of diegetic UI elements are a futuristic UI inside a helmet that provides vital stats and information or an in-game gadget that holds important clues for a player.

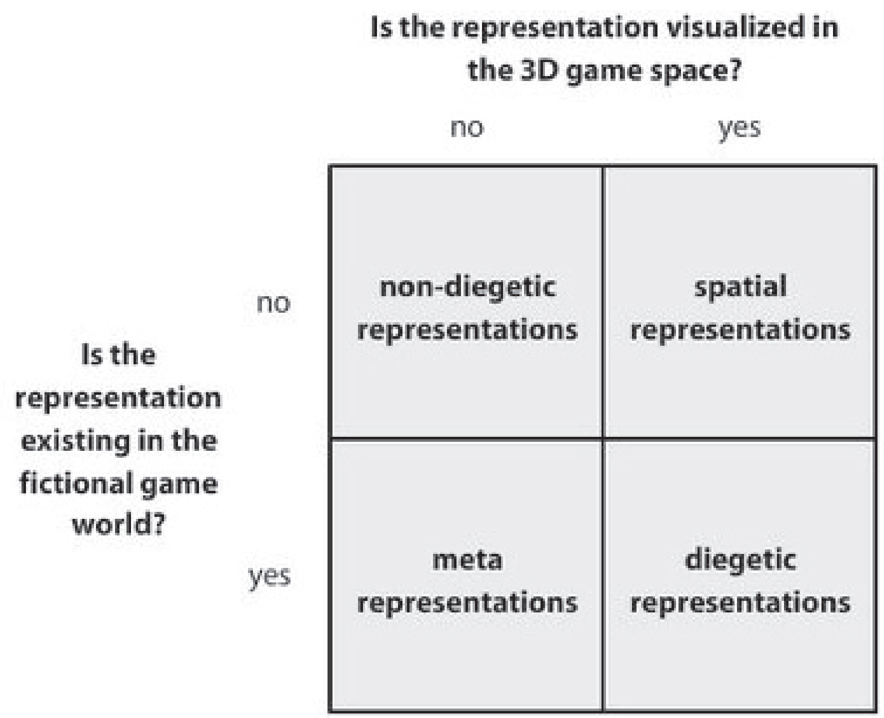


Figure 3-55: Charts on game UI typology, Fagerholt and Lorentzon [103]

- **Spatial** UI elements are displayed in the 3D space of the game but are not part of the game narrative. Their purpose is to provide additional information to the player. Examples include selection auras, highlighted wayfinding, and object text labels.
- **Meta** components are part of the game narrative but not in the game space. These elements give players information that is relevant to the game's story, such as blood splatters on the camera to indicate damage or coloured filters that represent the player's resource or life status.

By using this chart, game designers can determine which UI elements would best match the game's narrative and promote immersion while still fulfilling their primary function of conveying vital information to the player. A well-designed UI that balances immersion and functionality can enhance the player's overall experience and increase the game's replayability.

However, this analysis will focus on the diegetic and non-diegetic UIs in video games, and through this lens, identify common patterns in their design. The primary purpose of UIs in games is to provide the player with essential information, whether it is presented as part of the game world or outside of it. Regardless of its type, a UI must be accessible and user-friendly and must be integrated seamlessly into the game's narrative.
Key elements in video game UIs are the menu and user status information, such as lives, ammunition. For example, in the Figure 3-56, from "Battlefield V Firestorm", it is noticeable how the menu, open on weapon selection, and the most crucial information about ammunition and lives are detached from the environment narrative and therefore are non-diegetic. Whereas in Figure

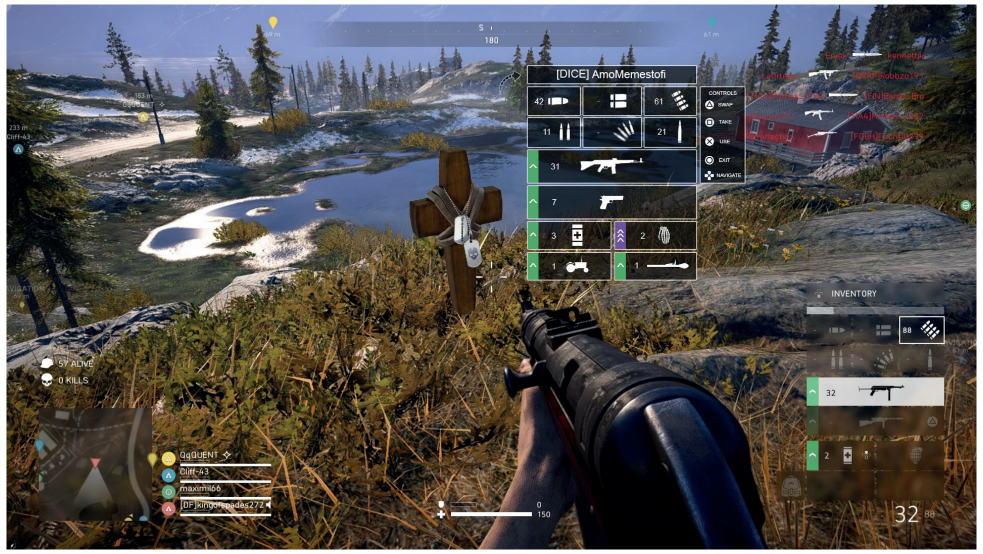


Figure 3-56: UI non-diegetic from Battlefield V Firestorm

Figure 3-57: UI diegetic from Freediver: Triton Down

3-57, from “Freediver: Triton Down”, basic information is shown in interfaces that attempt to be included in the narrative and belong in the context. Another successful example is from “Dead Space 2” in Figure 3-58, where the player’s health is displayed as a literal bar on the spine of the player character, Isaac. “Dead Space 2” is one of the most frequently cited examples of the efficient use of diegesis in video games. At the Game Developer Conference in 2013, the Visceral Games’ lead UI Designer Dino Ignacio explained the effort made to apply the diegetic concept in sounds and UIs to increase immersion [109]. The audio designers used only the ambience sounds of the ship, trying to emphasise its industrial environment, with metal, gear and engine sound without having background music, typical in video games, to give more importance to the ambience sounds.

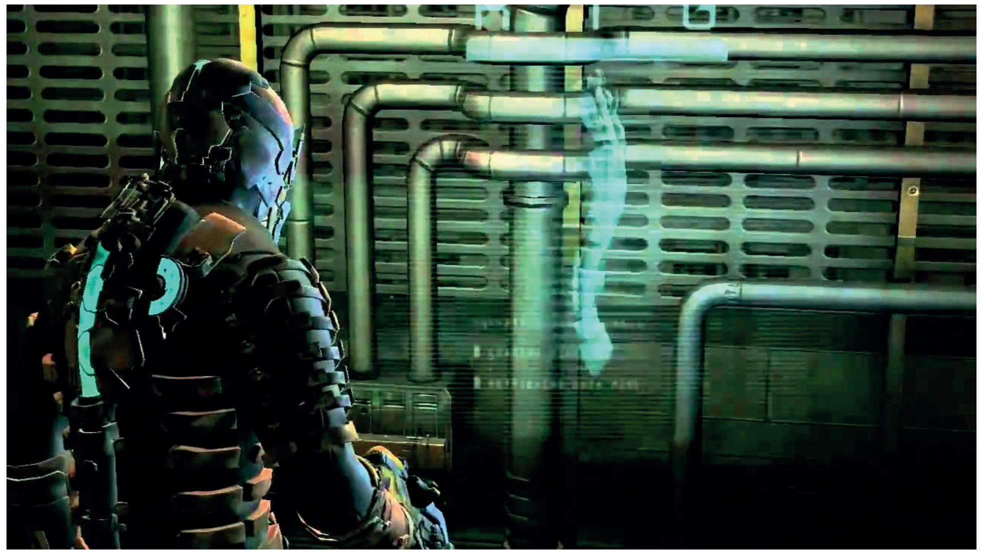


Figure 3-58: UI diegetic status bar from Dead Space 2

For the UIs, the designer tried to show all the elements that usually require an interface, such as a map, menu and inventory, diegetically. Another fundamental UI element is the directions, in most cases, a map to help the player navigate the video game. The Figure 3-59, from the video game “Legend of Zelda: Breath of the Wild”, is an example of non-diegetic UI in that the map is a GPS-style element that follows the player’s movements, not immersed in the context. While the Figure 3-60, from “Red Dead Redemption 2”, we have an example of diegetic UI in that the element is fully immersed in the context and narrative.

Figure 3-59: UI non-diegetic map in Legend of Zelda

Figure 3-60: UI diegetic map in Red Dead Redemption 2

Another example of diegetic UI is the use of the map in Figure 3-61 from the video game “Far Cry 2”. An attempt to make this element as immersed in the narrative as possible is from “Dead Space 2” in Figure 3-62, where the map is a holographic element in a futuristic environment.

Figure 3-61: UI diegetic map in Far Cry 2

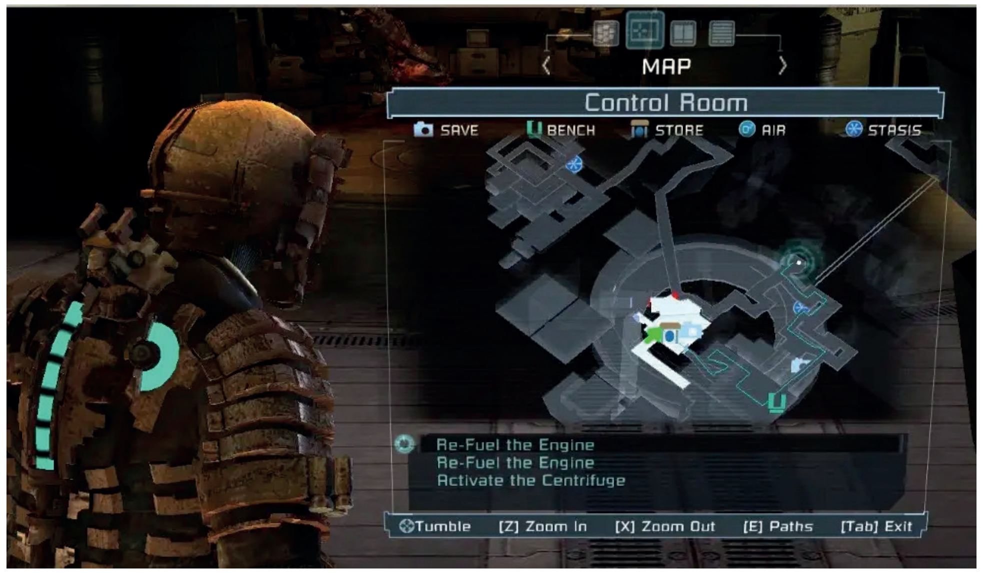


Figure 3-62: UI semi-diegetic map in Dead Space 2

Another essential UI element is information about the tasks/missions to be done. An example of non-diegetic is found in Figure 3-63, taken from the video game “Battlefield V”, where the upcoming tasks are inserted as text in the player’s central view. In contrast, an example of diegetic is in Figure 3-64, taken from the video game “Last Light”, where the tasks are in the form of a diegetic tool that matches the narrative and atmosphere.

Figure 3-63: non-diegetic UI for tasks in Battlefield V

Figure 3-64: diegetic UI for tasks in Last Light

In conclusion, analysing the patterns of diegetic and non-diegetic UI from video games has been crucial in finding effective solutions the experiment pianification. By understanding how UI elements can be integrated into the game's narrative and environment, designers can create immersive experiences that provide critical information to the player without detracting from the game's overall story. The examples presented in this analysis have shown how both diegetic and non-diegetic UI can be successful when designed with accessibility and usability in mind. As technology continues to advance and gaming becomes more sophisticated, understanding and applying these patterns will be increasingly important in creating compelling and engaging experiences for players.

Learning process through VR

This section provides an overview of the literature on the use of VR for learning processes, with a focus on pedagogy and experiential learning. Additionally, case studies are examined that utilize VR to facilitate early training and career selection.

Pedagogy

The term "pedagogy" encompasses both the theoretical and practical aspects of teaching, including designing, delivering, and evaluating instruction. The word itself comes from the Greek words "paidos," meaning child, and "agogos," meaning leader. Pedagogy is shaped by an educator's teaching beliefs and requires a deep understanding of the subject matter, the learners, and the learning process [110]. It's important to differentiate between pedagogy, learning, and training. While pedagogy deals with the methods and practice of teaching, learning refers to the process of acquiring knowledge, skills, and attitudes through experience, study, or instruction [111]. Learning is a cognitive process that occurs within the learner's mind and is influenced by various factors such as motivation, prior knowledge, and feedback. Training, on the other hand, is a process that focuses on teaching specific skills or knowledge for the purpose of preparing individuals for specific roles or tasks [112]. It is often more structured and goal-oriented than education and is focused on the acquisition of specific competencies. Training can be used to develop skills in various fields, such as job-specific skills, athletic skills, or even social skills.

The experiential learning theory

David Kolb, a psychologist, proposed a more holistic approach to pedagogy, known as the experiential learning theory [113]. This approach emphasizes how experiences, including cognition, environmental factors, and emotions, influence the learning process. Experiential learning occurs through direct experience or hands-on activities, in which learners actively engage in an experience, reflect on it, and use the knowledge gained to inform future actions [114]. Kolb's work was influenced by other theorists, including John Dewey, Kurt Lewin, and Jean Piaget. In 1984, he developed the "experiential learning cycle, shown in Figure 3-65, " which consists of four stages: concrete experience, reflective observation, abstract conceptualization, and active experimentation. This cycle provides a framework for learners to engage in a continuous process of learning and reflection, which helps them develop practical skills and knowledge that can be applied in real-world situations.

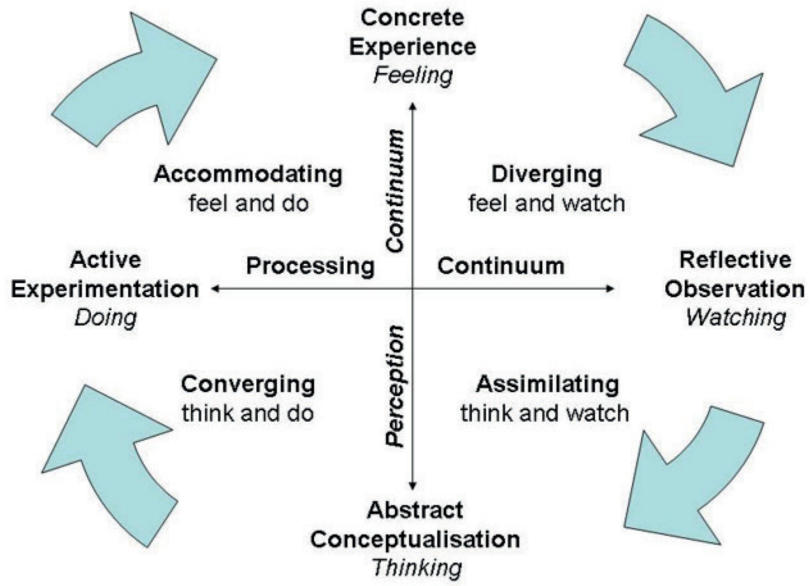


Figure 3-65: Kolb's experiential learning cycle model.

The experiential learning cycle is a cyclical process that repeats continuously, with each stage informing the next. The cycle begins with concrete experience, in which learners gain new experiences or interpret past experiences in a new way. The next stage is reflective observation, where learners assimilate and distill their reflections into abstract concepts, from which they can draw new implications for action. In abstract conceptualization, learners form new ideas or adjust their thinking based on the experience and their reflection about it. Finally, in active experimentation, learners apply their new ideas to the world around them to see if there are any modifications to be made. Kolb explains that these processes can occur over a short or long period of time, and that learners have their own preferences for how they enter the cycle of experiential learning, which is known as their learning style. By identifying and understanding their preferred learning style, learners can more effectively engage in the experiential learning process and achieve better learning outcomes [115].

Experiential learning in VR

The use of VR technology has opened up new possibilities for experiential learning, allowing students to engage in hands-on activities and explore places that would otherwise be inaccessible, such as seeing a historical building from the ancient world. The immersive and interactive nature of VR can enhance the learning process, as it allows students to experience situations and gather knowledge in a way that closely resembles direct experience [116, 117, 118]. In an experiment [119], the experiential learning process turns out to be improved with the use of VR due to an optimal and constant level of presence and haptic interaction in the experience. The use of virtual technology allows the users to recognize virtual experiences as direct experiences closely, enhancing the learning effect. In general, VR technology can be used as a tool for enhancing the pedagogical process in education by providing immersive and interactive learning experiences. According to some studies, [120, 121] VR technology can improve students' engagement and motivation in learning, as well as their ability to retain and apply information and VR can lead to increased cognitive engagement and problem-solving skills in students. In addition, it can also be used to provide students with virtual field trips, simulations, and other experiences that would otherwise be difficult or impossible to replicate in a traditional classroom setting. However, it is important to note that the effectiveness of VR in education depends on the quality of the VR content and the pedagogical approach used [122]. Therefore, it is crucial to carefully design and evaluate VR educational materials and activities to ensure they align with learning goals and effectively support the pedagogical process. Therefore, it is essential to carefully design and evaluate VR educational materials and activities to ensure they align with learning goals and effectively support the pedagogical process. It is worth noting that the benefits of using VR for learning may vary depending on the field of application, as it has been found to be particularly useful in medical education and psychology for improving skills and memory retention, respectively [123, 124, 125]. Nonetheless, VR technology has shown positive outcomes in education, such as increased intrinsic motivation, improved learning outcomes, and increased interest in learning.

VR technology enhances experiential learning by providing immersive and interactive experiences, which improve students' engagement, retention, problem-solving skills, and interest in learning.

However, ensuring that the VR content is of high quality and aligned with the learning objectives is crucial.

Occupational choice and vocational education in VR

Occupational choice refers to the process by which individuals select a career or trade to pursue through vocational training. Upon finishing primary and secondary education, students often struggle with deciding on a future occupational choice and assessing job opportunities. Choosing a career can greatly impact a student's future success or lead to disappointment if decisions taken are not based on proper information. Futhermore, this choice can be influenced by a variety of factors, including personal interests, skills, and abilities, as well as societal and economic factors. Young job-seeker should adequately informed when making decision in occupational choice and job opportunities. Vocational education, also known as career and technical education, is a form of education that focuses on preparing individuals for specific trades or careers. This type of education typically involves hands-on training and the development of practical skills that are directly applicable to a particular job or industry. According to the National Center for Education Statistics (NCES) [126], vocational education programs are typically offered at the secondary and postsecondary level, and may include courses in areas such as health care, manufacturing, construction, and information technology. These programs can lead to a certificate or diploma, or may be part of an associate's or bachelor's degree program. The NCES also reports that vocational education can help individuals enter the workforce more quickly and provide them with the necessary skills and knowledge to excel in their careers. Furthermore, vocational education can help meet the workforce needs of specific industries, and provide opportunities for career advancement. It is essential that students receive adequate guidance and support when making occupational choices. Vocational education can play a vital role in preparing students for the workforce, and equipping them with the necessary skills and knowledge to succeed in their chosen careers. Proper vocational training can help students make informed decisions, identify their interests and strengths, and provide access to various job opportunities. By offering vocational education programs, educational institutions can create a pipeline of skilled workers, meet the demands of specific industries, and drive economic growth.
One method for choosing a vocational job is to take career assessments or

Occupational choice is crucial and vocational education plays a significant role in preparing individuals for specific trades or careers and making informed decisions.

interest surveys, which can help identify careers that align with your interests and skills. Websites such as the U.S. Department of Labor's O*NET (Occupational Information Network) [127] or the Myers-Briggs Type Indicator [128] can provide information on different jobs and industries, as well as the skills and personality traits that are typically required for those careers. Another method is to research and explore the different jobs and industries, visiting job fairs, or attending informational interviews to learn more about the day-to-day tasks and responsibilities associated with different jobs [129]. Additionally, another way is to gain some experience in the field by volunteering, interning or job shadowing.

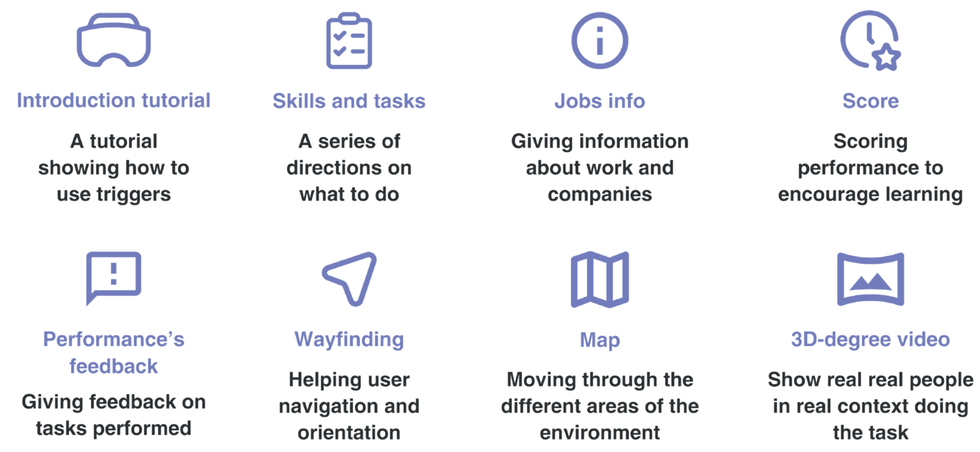
VR in this process has the potentialities to transports students to unfamiliar places and provides them with new perspectives, exposure to certain experiences, interact with certain professionals who may never be able to do without. A recent meta-analysis showed that the use of VR in primary, secondary and higher education increases learning success, especially with short learning contents [130]. The Boys & Girls Clubs of Indiana [131] have had success using virtual reality simulations to teach students about career opportunities through a variety of job-related simulations. A great research value is also provided by NTNU's IMTEL research group, which with the VR4VET project and the concept of 'Immersive Job Taste' [132] aims to give young job seekers a feeling of going through an average workday of a professional with elements of basic training. The VR experience includes a workplace presentation, typical tasks, feedback on performance, and advice on applying for jobs in the specific industry. These VR applications can provide a valuable tool for students and job seekers to explore career options and gain practical experience in a safe and immersive environment.

VR technology can provide students with new perspectives and experiences, improving learning success. In addition, it can be a valuable tool for exploring careers and gaining practical experience.

VR4VET: Virtual reality in career guidance and counseling

VR4VET is a project led by NTNU and the research group IMTEL, involving several partners in Norway, Germany and Netherlands, and concerns the development of VR-based career guidance methods. VR4VET started as another project, Virtual Internship, which consists of several prototypes created by NTNU students for the immersive job tasting collected in a catalogue of VR simulations. These prototypes are characterised by design guidelines that define their general components, as synthetize in Figure 3-66.

Figure 3-66: Components of the VR4VET simulation experiences.



Some examples of these that I have had the opportunity to test with the user target are Fishery VR, Wind turbine electrician and the CarpenteryVR.

The **Fishery VR app**, in Figure 3-67, offers a virtual simulation with multiple fish cages, a feeding station, and a fish processing facility. Users can immerse themselves in various scenarios replicating everyday work environments in the fishing industry. These include inspecting fish cages, feeding salmon, navigating a boat around the fjord, sorting and packing fish, and fillet cutting.

Figure 3-67: Fishery VR app.

The **Wind Turbine Electrician VR app**, in Figure 3-68, replicates a conventional wind turbine site and enables users to explore a turbine's interior and exterior thoroughly. The user is presented with a service challenge and can complete various tasks, beginning from the ground level, ascending to the peak, and executing additional duties. This application was created in collaboration with a nearby energy corporation.

Figure 3-68: Wind Turbine Electrician VR app.

In the **Tinsmith VR app**, the young jobseeker can simulate typical sheet metal fabrication activities at a workshop, a residential property, and outdoors on and around a high-rise structure. Users are prompted to choose a tin plate model and use scissors, cutting machines, and bending equipment in the virtual shop to construct it. Additionally, the application enables users to learn how to assemble a ventilation system using modular ventilation pipe segments and install a window fitting on the exterior of a building. The final task requires the user to waterproof a roof by fastening metal sheets along the edges with a pop-rivet gun.

Figure 3-69:
Tinsmith VR app.

Summarizing the findings

The diagram shown in Figure 3-70 outlines the main focus points of the research, schematised and divided by components and factors. It concerns what has been found of interest in the state-of-the-art literature, with on the left side what can be valuable for creating the hypothesis and on the right side what needs to be paid attention to when formulating them. The diagram is meant to take a snapshot of the state-of-the-art of literature research and identify opportunities and challenges.

Figure 3-70: Summary of opportunities and possible challenges identified in the state-of-the-art of the scientific literature.

04

User research

Following the reflection on the literature research phase, this chapter presents the phase leading up to the experiment hypothesis and testing. The research methods of the user target and the factual context are described here, resulting in the design opportunities and design requirements of the experiment execution.

Target user

What was evident from both the concept map and the literature research is that the young job seekers identified the user target of this research, as shown in Figure 4-1. That is because the research is positioned in the "early training" phase, meaning when individuals decide to enter the workforce and begin to develop skills relevant to their chosen careers. The target user is, therefore, demographically the most suitable as they seek guidance and motivation during this phase.

Young job seekers are individuals between the ages of 16 and 25 who choose alternative vocational education or opt directly for working life. They are typically interested in gaining practical experience and skills to help them choose and succeed in their chosen career. Very often, they may also be tech-savvy, comfortable with digital technologies and online learning, and open to new ideas and experiences.

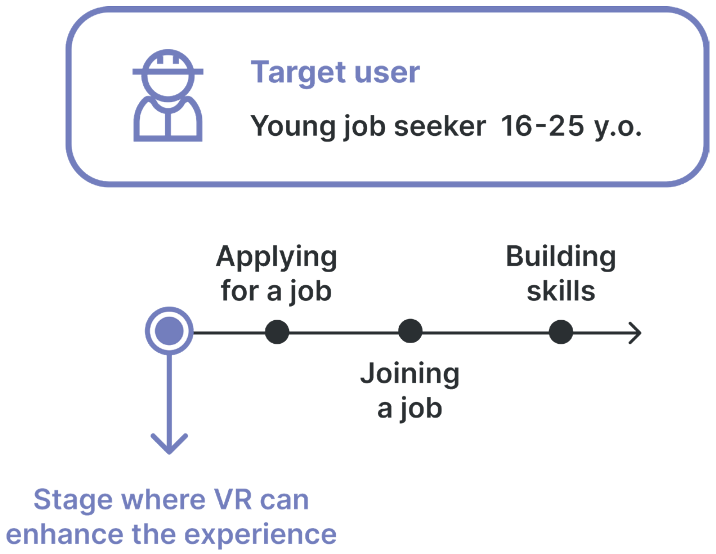


Figure 4-1: Target user and stage where VR can enhance and make the experience useful

Research methods

To support the ideation, planning and development of the experiment, different qualitative research methods have been chosen. The methods, synthesized in Figure 4-2, include a series of interviews with experts in the field of construction and user testing and usability testing on previous VR experiences of the VR4VET project. Additionally, a collection of case studies on similar experiments utilizing immersive technology was gathered.

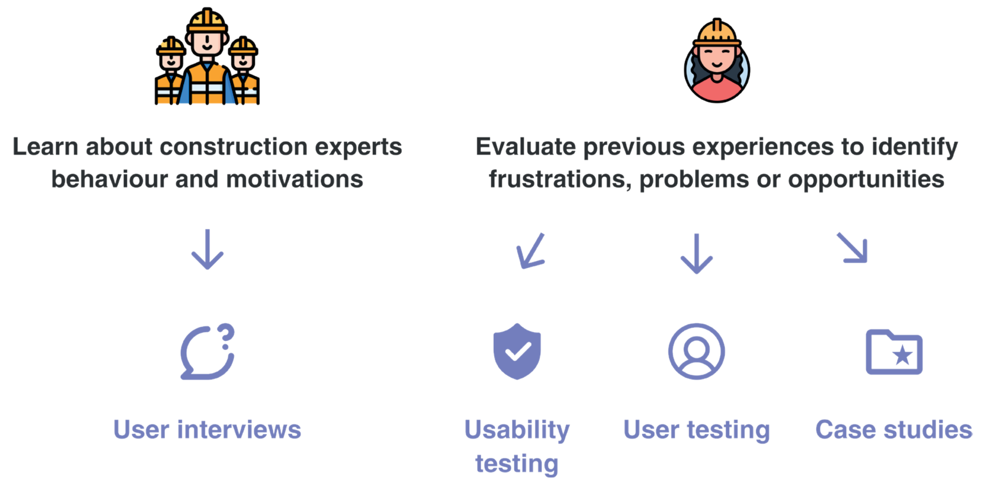


Figure 4-2: Research methods synthesis.

Interviews with construction experts

In the context of design research, interviews can be used to gather insights from users, stakeholders, or experts in a particular field. Professionals and experts in the construction sector were interviewed to gain insights into their personal experiences, habits, and perspectives. It was important to interview different roles of construction site experts because each role brings unique insights and perspectives that can help create a more accurate and realistic virtual environment. For example, a construction manager may have a broad understanding of the overall site layout and construction processes, while a surveyor may have detailed knowledge of the site's topography and features. By interviewing a range of experts, VR developers can ensure that the virtual environment reflects the diversity and complexity of the real-world site. It can help ensure that the VR experience is accurate, relevant, and useful for its intended target user, and can help identify new opportunities for leveraging VR strategies. The interviews were designed to include both structured questions about their daily routines as well as open-ended discussions about the training of young job seekers entering the field. The ultimate goal of these interviews was to generate insights that could inform the design process.

Procedures

In the interviews, a one-to-one format was used with ten structured questions followed by an open discussion. The questions were asked directly to each individual, who provided verbal responses. The process was recorded using audio and later transcribed for analysis. The insights gathered aimed to identify both contrasts and similarities between individuals, seeking patterns in their responses.

The ten structured questions were as follows:

1. What tools do you consider essential for your work?
2. Can you briefly describe a typical working day, including how it starts, such as preparing materials and assigning tasks, and how it continues throughout the day?
3. What tasks do you typically perform most frequently during a workday?
4. Which tasks do you consider crucial and essential for the success of your work?
5. How much time do you usually allocate to each task or activity?
6. If you had to train young people, which activities or tasks would you assign to them?
7. If you haven't trained young people before, what tasks would you recommend for them? Is there anything specific that motivates you every day in your work, apart from financial incentives?
8. How long do you think it takes to gain the confidence to perform optimally in your field of work?
9. Can you recall the initial tasks that you were given when starting your first work experience?
10. What advice would you give to a young person who has recently entered the workforce in your field?

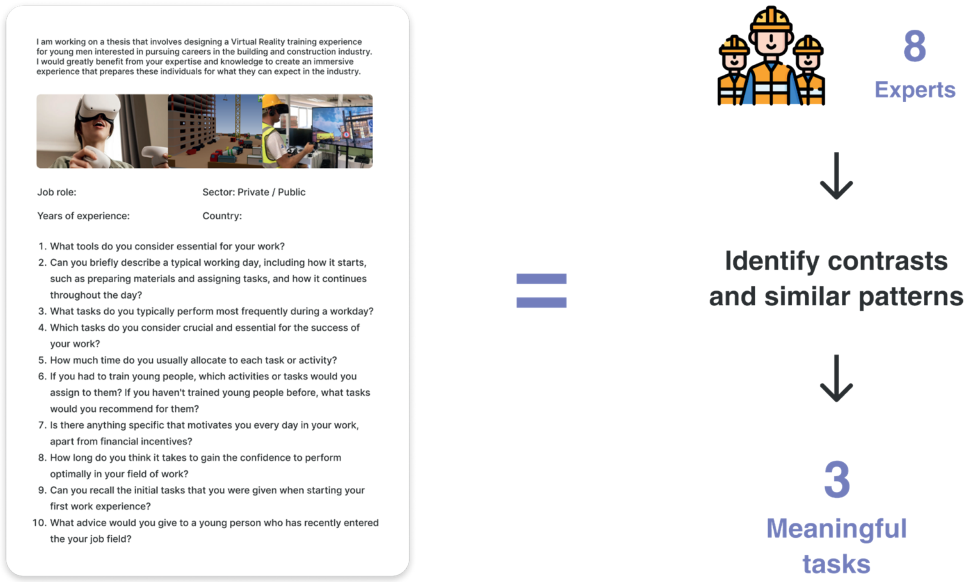
A total of 8 professionals and experts in the construction sector were interviewed. They hailed from different countries and had varying backgrounds within the field. As a result, the research gained valuable insights into the daily routines and essential activities within the field. Furthermore, by analyzing the data collected from the interviews, the interviewees identified three critical tasks. These tasks were deemed essential and included the preparation of materials, equipment handling, and team communication.

Key findings

Through the ten structured questions, shown in Figure 4-3, the research successfully identified three potential tasks that could simulate a realistic work environment for young individuals interested in pursuing a career in the building and construction sector. These tasks will be integrated into the VR training experience, providing aspiring professionals a deeper understanding of the industry's demands. In addition, using structured interviews proved to be a valuable research method, providing essential insights and significantly contributing to the experimental project.

Through the series of interviews with construction site experts, it has become clear that three tasks are particularly important in the construction industry: creating concrete, measuring room dimensions with tools like laser level, and fixing electrical wires. These tasks were consistently highlighted by the experts as being critical to successful construction projects. Creating

Figure 4-3: Key insights of the interviews as a research method.



concrete is a foundational element and requires careful attention to the mix of ingredients, the timing of the pour, and the curing process. Construction site experts emphasized the importance of using the correct ratio of ingredients, ensuring that the concrete is poured in a timely manner, and allowing it to cure properly before continuing with the project. Measuring room dimensions is another critical task in construction, and laser levels have become an increasingly popular tool for achieving precise measurements. Experts stressed the importance of taking accurate measurements in order to ensure that all elements of the construction project fit together properly. Even small discrepancies in room dimensions can have significant impacts on the overall project. Finally, fixing electrical wires was identified as a key task in the construction industry, particularly in the context of building new structures or renovating existing ones. Ensuring that electrical systems are installed properly and safely is critical to the success of any construction project and requires expertise and attention to detail.

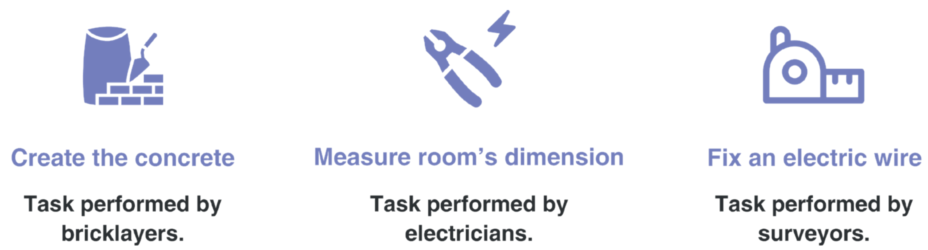


Figure 4-4: The three tasks chosen for the experiment.

Overall, these three tasks, shown in Figure 4-4, highlight the complexity and importance of the construction industry and the expertise required to ensure successful projects. By understanding the perspectives and insights of construction site experts, it is possible to develop more effective and accurate virtual reality experiences that can be used to train new workers, simulate complex scenarios, and improve safety and efficiency on construction sites.

User testing and usability testing on VR4VET experiences

User testing and usability testing were used as a method to evaluate the effectiveness and user-friendliness. User testing involves observing users interacting with a product or service and collecting feedback and opinions. This type of testing helps identify weaknesses, issues and areas for product improvement. On the other hand, usability testing focuses on evaluating a product or service's efficiency, measuring how easily and effectively users can complete specific tasks.

During my collaboration with the IMTEL research group for the VR4VET project, I was able to conduct both user testing and usability testing, evaluating some of the previous experiences created by the students that composed the VR catalog. These tests gave me the possibility to gain valuable insights about the strengths and weaknesses of each scenario, as well as identify areas for improvement. By listening to user feedback, the aim was to understand the main weaknesses from a design and narrative point of view and be able to provide young job seekers with an effective and enjoyable learning experience.

Figure 4-5: User and usability testing performed for the VR4VET project

Procedures

User testing and usability testing were conducted at the VR Lab at NTNU University, both before and after developing the thesis concept map and evaluating hypotheses. The tests were carried out using two widely used VR devices, HTC Vive and Oculus Quest 2.

Devices

HTC Vive

Oculus Quest 2 128gb

Software

Unity 3D

Figure 4-6: VR devices and software used for the user and usability testing.

Three main experiences of the VR catalogue of VR4VET were tested, namely FisheryVR, Wind Turbine Electrician and CarpentryVR. The user testing aimed to observe the behaviour of the users and assess how well they met their needs. This involved gathering feedback on how easy the applications were to use, how engaging they were, and how well they met their requirements. While the usability testing aimed to identify any potential issues with the interface design, user interactions, and overall user experience. Factors assessed include accessibility, intuitive interface design, and smooth interaction with the application. The majority of users who participated in the testing had no prior experience with VR technology. This proved to be an important factor in understanding how users interact with VR applications and what factors contribute to a successful experience.

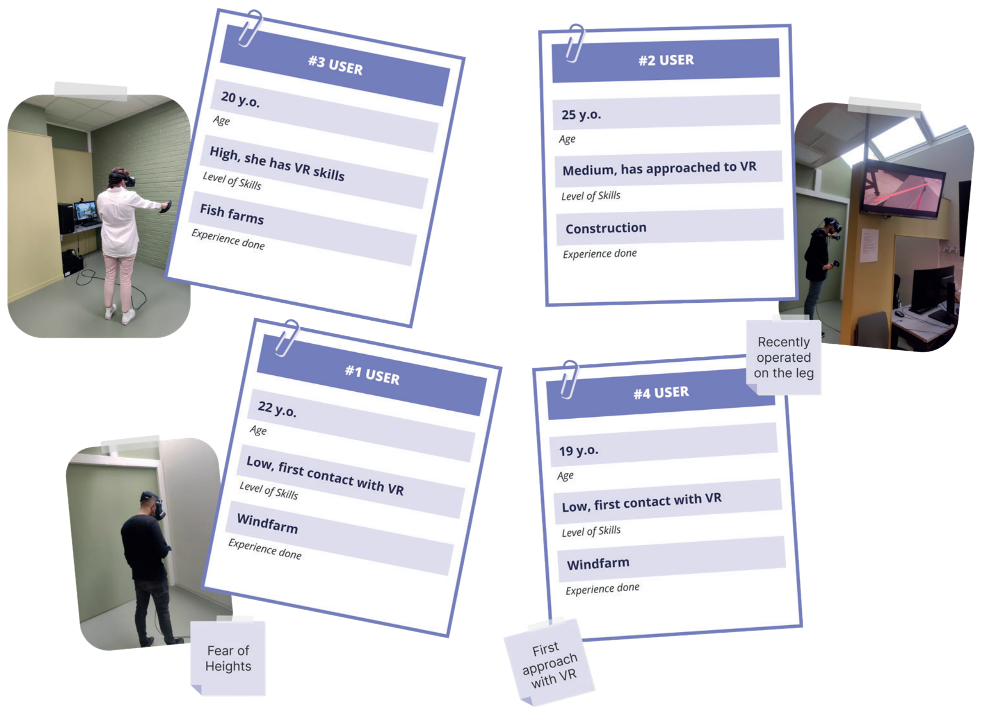


Figure 4-7: Some of the tests carried out, with the corresponding feedback collection.

Overall, the user testing and usability testing conducted at the VR Lab in NTNU were essential in understanding how users, especially the user target of young job seekers, interact with VR applications and what factors contribute to a successful experience. The feedback received from the tests was used to start planning the experiment and understand its requirements.

Insights and findings

As the experiences differed from a display and interaction fidelity point of view, I could see how the different variables affected the users. Some useful results to highlight are that:

- In general, an essential element is the initial tutorial. Providing a good tutorial on game mechanics at the beginning of the experience is crucial to ensuring a positive user experience. This helps users understand the basic controls and mechanics of the application, thus improving their engagement and overall satisfaction.
- Regarding display fidelity, a user having a phobia of heights was more comfortable having a low-fidelity scenario than a high-fidelity one. When she climbed to the highest point of the turbine, from where the landscape could be seen from above, she was not too frightened as the environment was one of the lowest fidelity experiences. She also really appreciated the possibility of opening the map and splashing the part about getting off the turbine to avoid straining her fears and having a negative experience.
- Regarding interaction fidelity, tests revealed that some users had difficulties with the controls and some elements of the applications, especially when they were in high fidelity. Users did not understand how to use objects directly, and often, the lack of feedback did not make them understand the end of an action.

Experiments case studies collection

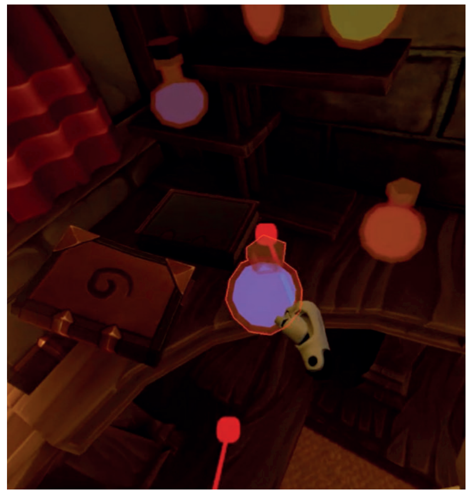
To acquire knowledge on how to efficiently design experiments, a study was conducted on scientific papers that experimented with the impact of display and interaction fidelity and diegesis levels on user performance in VR experiences. The research examined multiple papers, but three specific ones stand out as noteworthy case studies:

1. “Exploring Interaction Fidelity in Virtual Reality: Object Manipulation and Whole-Body Movements” [133];
2. “A study of how immersion and interactivity drive VR learning” [134];
3. “Video Game Interfaces and Diegesis: The Impact on Experts and Novices’ Performance and Experience in Virtual Reality” [106];

The first paper analyses the impact of the user experience with varying degrees of IF. To achieve this goal, two scenarios with distinct levels of interaction fidelity were created, one with low IF and the other with high IF, shown in Figure 4-8.

Figure 4-8: Low and high IF interaction in two different tasks.

Figure 4-8: Low and high IF interaction in two different tasks.



The experiment involved assigning three identical tasks to each scenario to enable comparative analysis. Participants included 26 users who were asked to try both scenarios, followed by a post-experience questionnaire to evaluate the cognitive perception and states such as immersion, engagement, and presence. One critical aspect of this experiment was the comparison of the two scenarios with different interaction fidelity levels and ensuring that the same tasks were assigned to both. This allowed for a fair and accurate analysis of the impact of interaction fidelity on user experience. The results of this experiment were that the high-IF scenarios resulted in more presence, enjoyment and real-world dissociation perceived by the users.

The second paper aimed to explore the impact of immersion and interactivity on learning outcomes in a virtual environment. To achieve this, researchers designed a laboratory scenario focused on educating participants about viral diseases. The study tested different combinations of media types, including video, PC, VR-video, and VR, to determine the effect of varying levels of immersion and interactivity on learning. In less interactive scenarios, participants watched a video where an expert spoke about the topic while demonstrating laboratory experiments. Conversely, in the interactive scenarios, participants were immersed in a virtual environment created using Unity, shown in Figure 4-9. The Unity environment enabled participants to interact with the laboratory equipment, conduct experiments, and explore different aspects of the topic in a more engaging and immersive way. By comparing the outcomes of the different scenarios, the study aimed to provide insights into how to optimize learning experiences in virtual environments.

Figure 4-9: Virtual museum exhibition built in Unity.

In the study, 185 participants were recruited and randomly assigned to one of four groups, each experiencing a different level of immersion and interactivity in the virtual learning environment. After completing their assigned experience, the participants were asked to complete a post-experience questionnaire to assess their learning outcomes and engagement. The results of the study showed that a high level of interactivity and immersion positively influenced the learning experience. Participants who were immersed in the virtual environment and had a high level of interaction with the content reported higher levels of engagement and learning outcomes compared to those who experienced less immersive and interactive environments. Moreover, the study also found that high levels of interactivity can reduce the extraneous cognitive load from the environment. This means that participants were able to focus their attention on the learning material rather than being distracted by the environment. High immersion was found to lead to greater situational interest, indicating that participants were more motivated to engage with the learning material in a realistic and engaging virtual environment.

The objective of the third paper was to investigate the impact of diegetic and non-diegetic elements on the performance of novice and expert users in a VR environment. The study presented two scenarios, one with diegetic elements and one with non-diegetic traditional Heads-Up Display (HUD) elements, as illustrated in Figure 4-10.

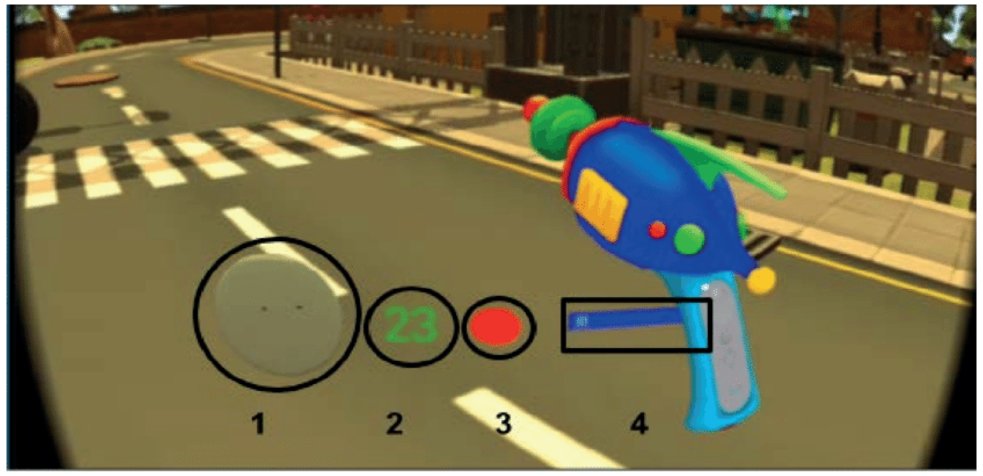


Figure 4-10: Diegetic and non-diegetic interface in the gun.

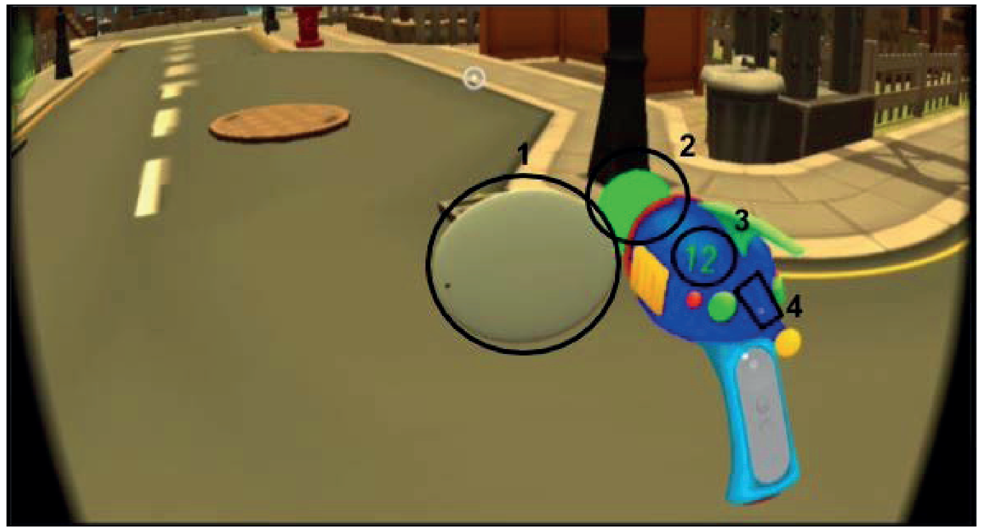


Figure 4-10: Diegetic and non-diegetic interface in the gun.

The tasks involved direct interaction with a gun, where the user was required to defend themselves against enemies while monitoring the ammunition level and lives. The study recruited 41 participants, who were asked to try both scenarios. The hypothesis was that expert users would benefit more from the diegetic scenario, providing a more immersive and realistic experience, while novice users would benefit from the non-diegetic scenario, as it would be easier to understand and use. However, the results were unexpected: novice users performed better in the diegetic scenario than in the non-diegetic scenario, while expert users showed no significant difference in performance between the two scenarios.

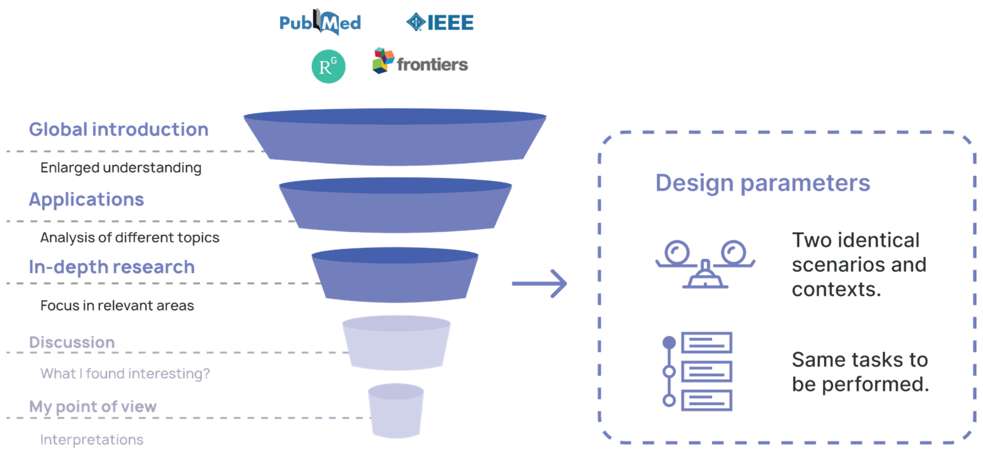
Procedures

The procedure was to perform a systematic literature review to identify relevant papers published in the last five years. Major databases such as IEEE, Research Gate, Frontiers, and PubMed were investigated. After formulating the hypotheses for this research, the collected papers were compared to identify similarities in research questions and methodologies used. This allowed defining a possible method for testing the hypotheses of this thesis. The methodology for testing was then discussed with the thesis's supervisors, who helped define a direction and put the experimentation into a valid perspective.

Insights and findings

Previous papers have highlighted the importance of carrying out a comparison experiment as a valid method for testing hypotheses. However, to ensure a valid comparison, it has been noted as crucial to use scenarios with similar or identical tasks and complexity levels in order to obtain accurate results on various parameters such as fidelity level and diegesis. Taking this into account, the researchers began to explore a possible experimental setup, which is illustrated in Figure 4-11. This setup was designed to ensure that the scenarios used in the experiment were comparable, thereby facilitating valid measurements of the assumptions being tested.

Figure 4-11: Insights and findings from the experiment's case studies collections.



Overall, it was essential to analyze scientific papers to develop a deep understanding of how to plan and execute VR experiments. Analysing them helped to understand what the weak points might have been and where to get inspiration for their effectiveness.

Summarizing the findings

Figure 4-12 summarises the results obtained from the user research, i.e. a type of comparative experiment, defined and identical tasks in the two scenarios to be performed by the users, and a possible way of conducting and measuring the experiment.

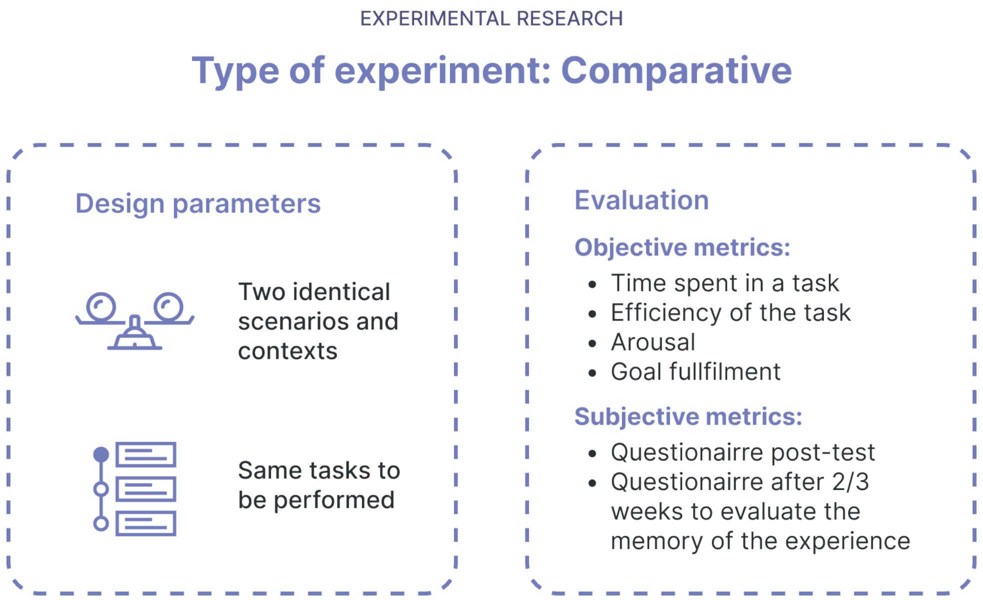


Figure 4-12: Summary of the user research.

05

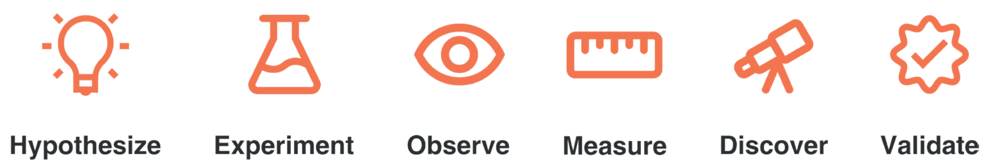
Experiment design framework

This chapter focuses on the steps that constitute the planning and execution of the experiment, explaining the method, experiment hypothesis and design requirements.

Experiment protocol

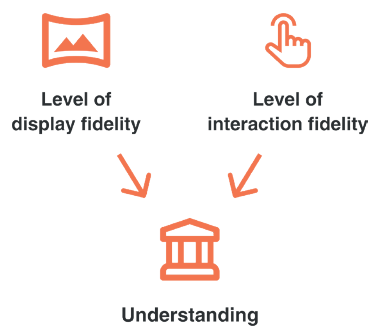
The exploration and synthesis of the state-of-the-art in Chapter 3 and the user research insights presented in Chapter 4 allowed for the identification of fundamental elements to proceed with the experimentation, which are the tasks to be performed in the scenarios and the measurement tools. Starting from the process method used for the development of the experiment, as shown in Figure 5-1 and based on the method explained in the book “Testing business idea” [11], the aim of this chapter is to define hypotheses, establish the design requirements and finally display the experiment design framework.

Figure 5-1: Design development process methodology.

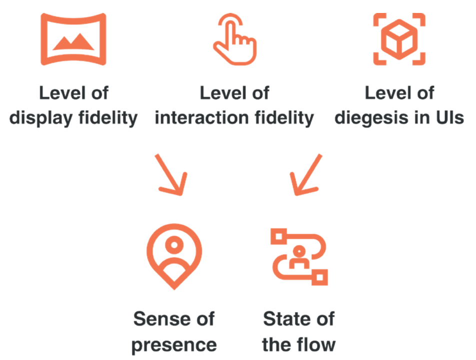


Hypothesis

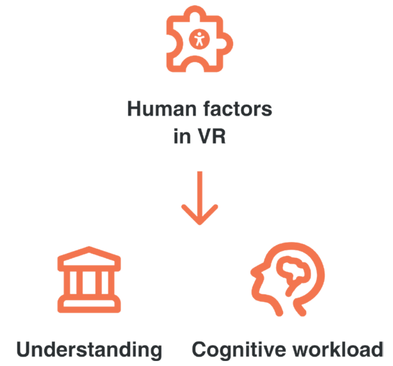
The hypothesis that emerged in the process of the research, and on which the experiment is based, are the following:



Providing a highly realistic environment in terms of display and interaction fidelity can enable users to gain a better understanding, comprehension and awareness of the simulated VR environment, resulting in a more accurate view of the job activities and workday routine. The memory that users retain following the experience can be used as a measure of effectiveness of this assumption.



Having a high level of realistic environment and diegesis of visual elements can contribute towards users feeling more immersed in the virtual experience and having a stronger sense of presence. The perceptions expressed by users following the experience can be used to measure this approach’s success.



Emphasizing adherence to human factor principles, such as accessibility guidelines and patterns that minimize cognitive effort in VR, can enhance the usability of the experience and enable users to achieve task goals with minimal mental effort. The performance time and perceived usability of the user following the experience can be used to measure the efficacy of this assumption.

Design requirements and measurements

After identifying the experimentation hypotheses, the first step was to define the design requirements and subsequent measurements. From the collection of case studies from other experiments, the need to construct two different scenarios was identified. As displayed in Figure 5-1, two scenarios were ideated: one with minimal display, interaction, and non-diegetic elements (low-fidelity), and another with high display realism, interaction, and diegetic elements (high-fidelity). The objective was to compare the two scenarios and measure their effects through usability tests and the completion of experiential and post-memory questionnaires.

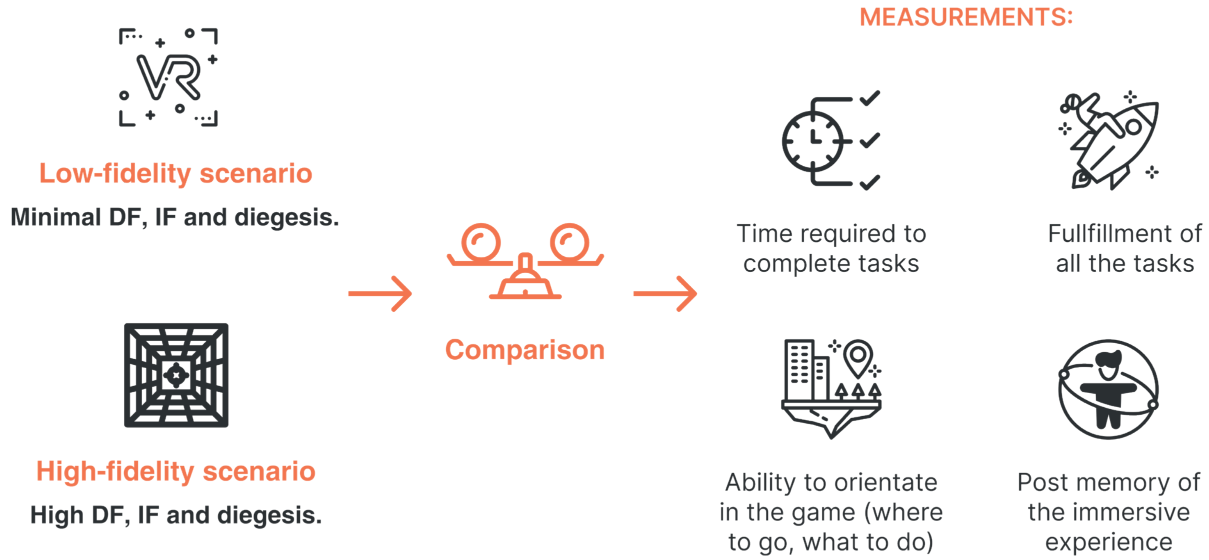
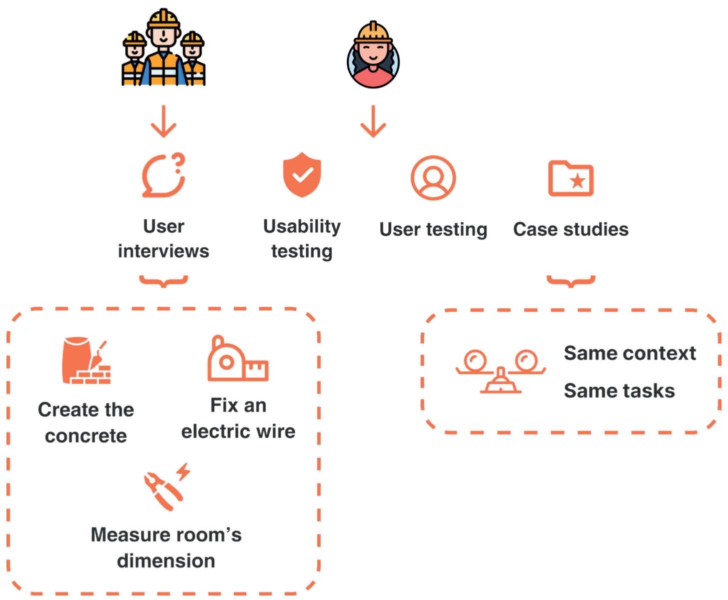


Figure 5-1: Design requirements and measurements.

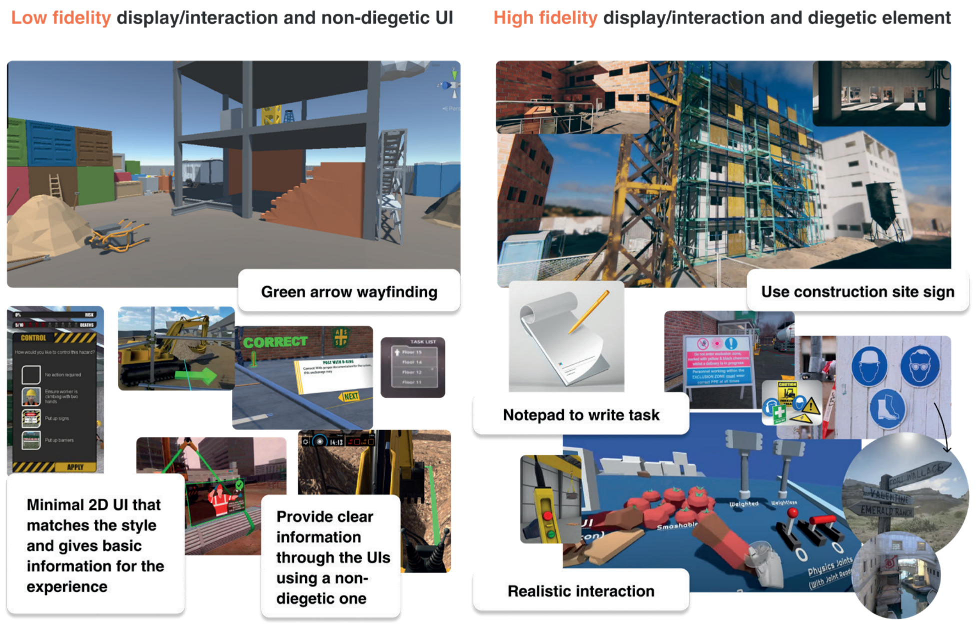
The tasks for the two scenarios were chosen based on the insight gained from the expert interviews. The selection of these tasks was further strengthened by the collection of case studies from other experiments, which helped to understand the need for comparable complexity and ease of implementation for low-fidelity and high-fidelity scenarios.

Figure 5-2: Task identification.



Afterwards, as shown in Figure 5-3, a simple low-fidelity prototype was developed to confirm the design choices for the two scenarios, which included the primary components, such as the visual style, mechanics, and a system for orientation and feedback.

Figure 5-3: Low-fidelity prototype of the two scenarios.



Experiment framework

Once the different ideas for the experiment's design were approved, the planning phase began. When conducting an experiment in VR, there are several important factors to consider, such as the equipment, the software, the participants, and the environment. Proper planning can ensure that these factors are addressed effectively and efficiently, leading to a successful experiment. As shown in Figure 5-4, the various steps of the experiment were defined.

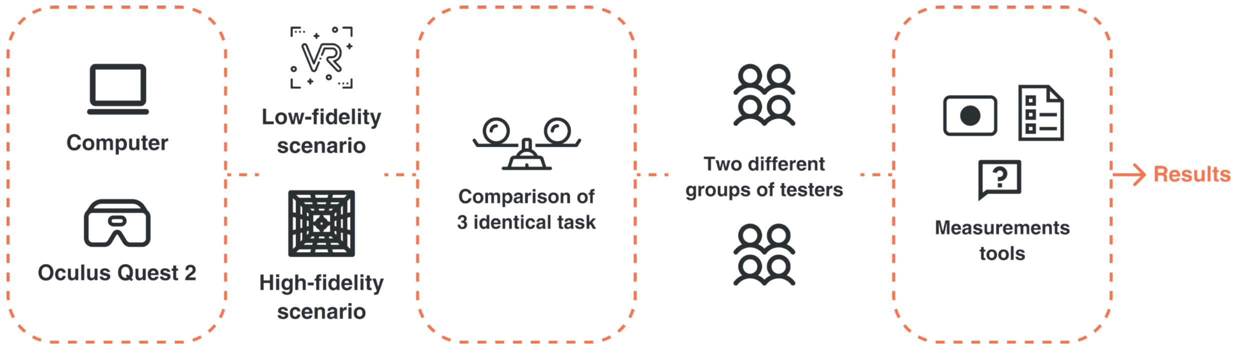


Figure 5-4: Experiment framework.

- A critical aspect of planning an experiment in VR is determining the appropriate equipment to use. In this case, the Oculus Quest 2 device was chosen for its effectiveness and simple design. The use of a computer was also planned in case the high-fidelity scenario required additional processing power to render the scenario.

- Another critical factor to consider is the selection of participants. Careful consideration must be given to the criteria for selecting participants, such as their age, gender, and experience with VR. Selecting the appropriate participants is essential to ensure that the data collected is representative and accurate. In this case, the target users were selected from first-year bachelor students in Civil and Engineering at NTNU, due to their interest in the construction field but lack of experience in a real context.

- Finally, planning must include consideration of the experimental environment. This includes factors such as lighting, sound, and the physical space in which the experiment will be conducted. Ensuring that the environment is conducive to the experiment can help minimize distractions and ensure the reliability of the data collected. In this case, the NTNU VR laboratory was chosen, which is a soundproofed environment equipped with everything necessary for the experiment.

06

Design development

This chapter will describe the first and second iterations of the development cycle. It dives deeper into the configuration of the two scenarios with their features and interactions, and the results of the usability testing performed on the prototype at the end of the first iteration.

Software and hardware tools

This section explains the software and hardware tools used, namely Unity and Figma, the platforms Sketchfab and Unity Asset Store and the Oculus Quest 2.

Unity

Unity is a versatile and widely used software tool for developing games and experiences. As a cross-platform game engine, it supports different platforms, including desktop, console, mobile, and VR devices. Unity offers several features and tools that help developers easily create high-quality interactive games, and its user-friendly interface allows developers to create games without extensive programming experience. However, developers can also write game logic using the C# programming language. For VR development, Unity provides built-in resources that facilitate the creation of immersive and interactive experiences. These resources can be easily imported into the editor and customised to meet specific requirements, such as in Figure 6-1 with the low-poly environment. A useful resource for the development of the two scenarios was VRTK, which stands for Virtual Reality Toolkit, a collection of reusable solutions that helps speed up the creation process and address common challenges when creating VR experiences.

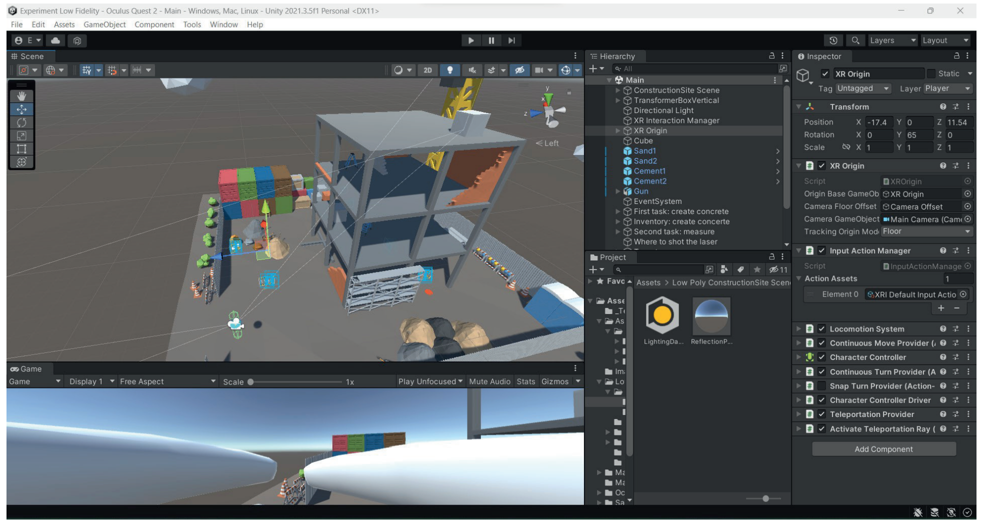


Figure 6-1: The low poly scenario shown in Unity.

Figma

Figma is a cloud-based design collaborative tool primarily used to create UI and UX designs. It has several features that make it stand the ability to create and share design libraries. While this platform was not initially designed for VR development, it has become a popular tool among VR developers due

to the large and active community of designers who share their design work, tutorials, resources, tips and tricks. The community has also created several plugins and integrations that enhance the platform's capabilities for VR development. For example, some plugins allow designers to import 3D models into Figma, making it easier to create VR designs. In this research, Figma's value was the accessibility monitoring for the 2D interfaces for the low poly scenario and the creation of signs for the high fidelity scenario. Accessibility was tested using the Contrast plugin, which allows designers to check the contrast ratio of text and background colours. It is essential to ensure that the content is legible and accessible to everyone, including those with visual impairments.

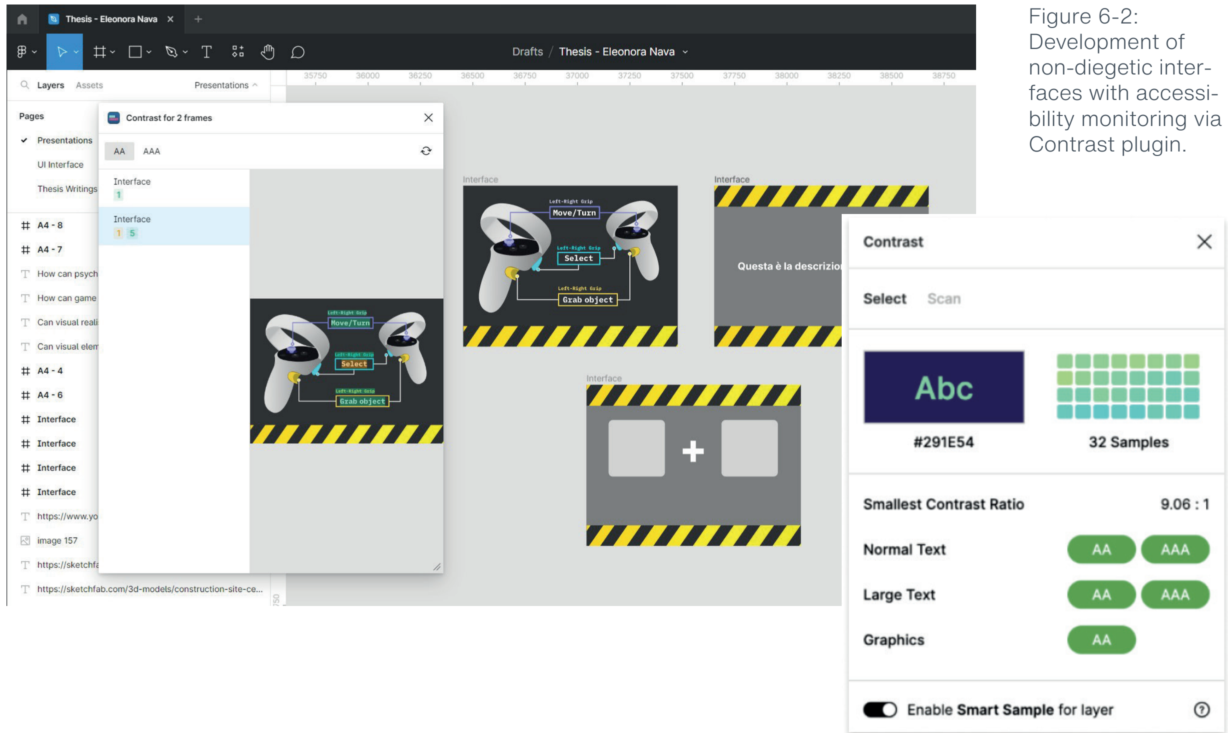


Figure 6-2: Development of non-diegetic interfaces with accessibility monitoring via Contrast plugin.

Sketchfab and Unity Asset Store

Sketchfab and Unity Asset Store are valuable resources for developers creating 3D graphics and VR applications. They offer access to a vast library of pre-built resources and the ability to showcase and sell 3D content. These resources can save time and effort in the development process, allowing developers to focus on creating high-quality and immersive VR experiences. In particular, Sketchfab is a platform that allows developers to share and discover 3D models, VR environments, and animations. It hosts a vast library of user-generated content, including models and animations that can be used in VR applications. On the other hand, Unity Asset Store is a digital marketplace for Unity game engine users to find and purchase various digital assets, including 3D models, textures, animations, scripts, and plugins.

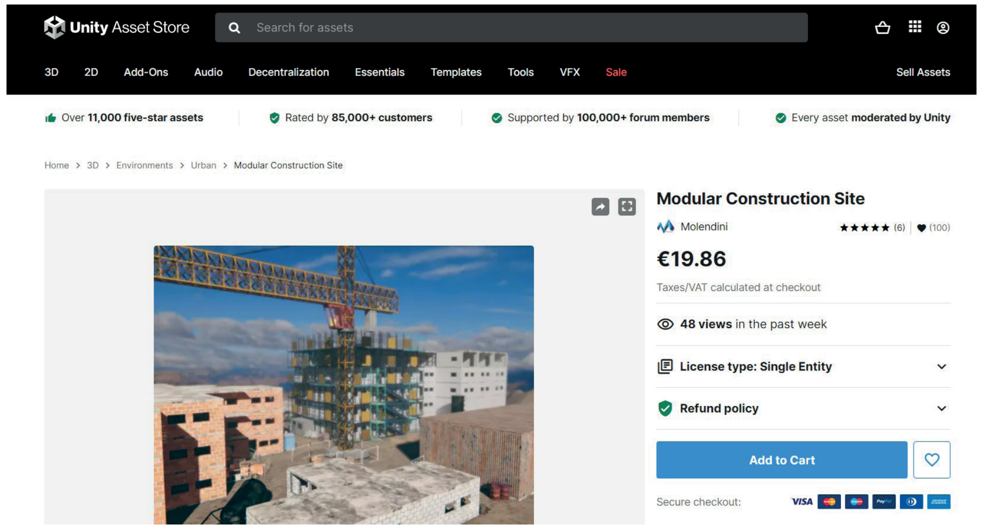


Figure 6-3: Unity Asset Store and Sketchfab.

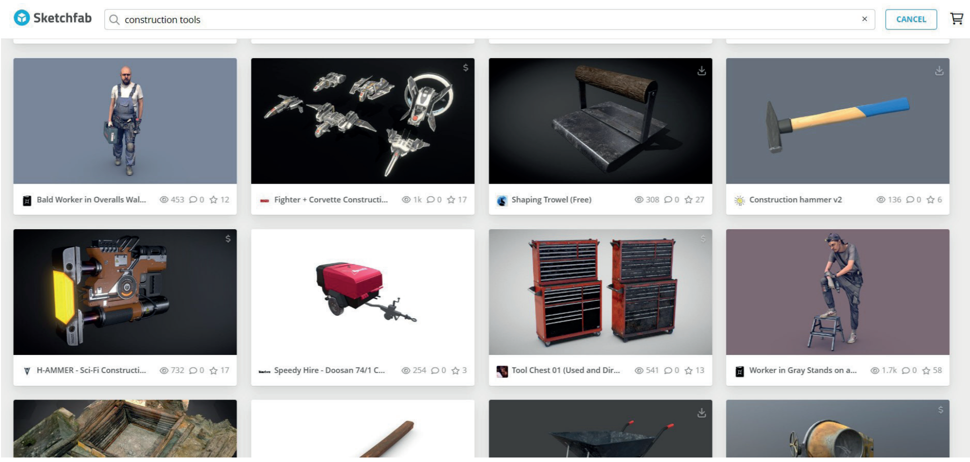


Figure 6-3: Unity Asset Store and Sketchfab.

Oculus Quest 2

Oculus Quest 2 is the second-generation headset from Oculus that boasts various features, making it an excellent hardware option for VR application development. One of its standout features is its wireless and standalone design, which allows developers to create VR applications without needing an external PC or console. This feature also allows for more flexibility in VR development since it can be used in any environment. Additionally, the Oculus Quest 2 delivers high-quality visuals and sound, enhancing the VR environment's immersive experience. The headset's resolution is 1832x1920 pixels per eye, resulting in sharper and clearer images compared to the original Quest. The integrated speakers also provide spatial audio, improving the overall VR experience. Another benefit of the Oculus Quest 2 is its large and growing user base, making it an attractive platform for developers. The platform provides a range of development tools and resources, including the Oculus SDK and Unity integration, which simplifies the creation of VR applications.

Figure 6-4: Oculus Quest 2.

First prototyping iteration

This section provides an overview of the technique-level design of the environment and tasks.

Search for 3D models, UI style research and diegesis integrations

Before going into the design of the tasks,two scenarios were chosen to represent the two different types to compare. Two pre-designed models were downloaded from the Unity Asset Store, specifically "Low Poly Construction Site" and "Modular Construction Site".

Figure 6-5: Low Poly Construction Site Assets.

Figure 6-6: Modular Construction Site Assets.

Then, all the 3D models of both low and high fidelity were downloaded, which would be useful in composing the tasks, such as billboards to place the tasks in the high fidelity environment, and tools like shovels, concrete mixers, laser levels, and pliers, as shown in Figure 6-7 and 6-8. These were mainly downloaded from Sketchfab, given the wide selection of materials available.

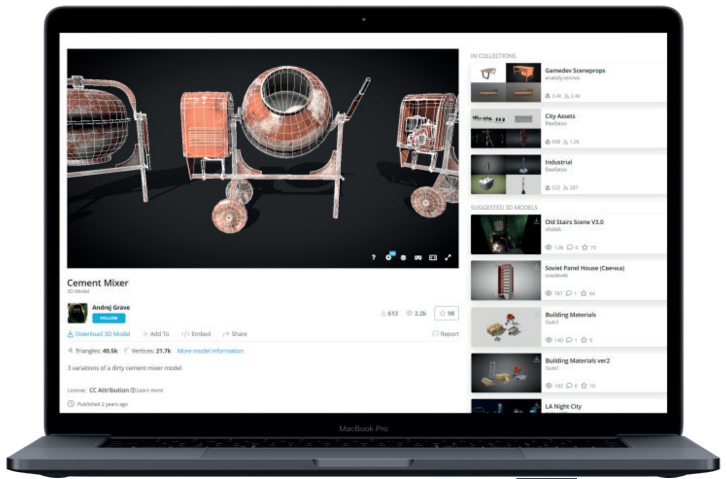


Figure 6-7: Concrete mixer model in Sketchfab.

Figure 6-8: 3D models for high-fidelity scenario.

After finding various pre-made models useful for composing the scenarios, a style search was conducted to identify how to design non-diegetic UI and how to integrate diegetic elements. As for non-diegetic interfaces, other VR experiences in the field of construction sites were searched to understand how interfaces and feedback were managed.

Figure 6-9: Style insight collection for non-diegetic interfaces.

In this way, a style was created that recalled the world of construction, and a simple design system of elements such as buttons and text styles was built, which respected factors such as usability and accessibility.

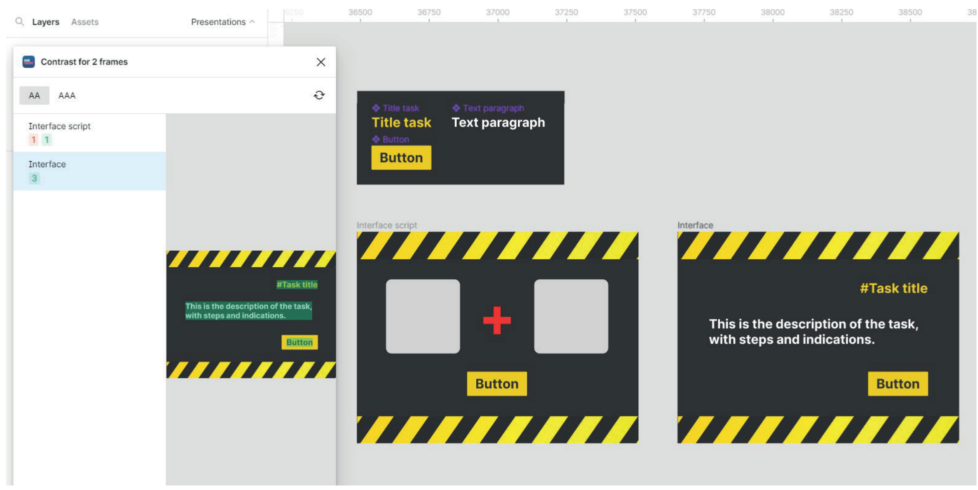


Figure 6-10: Building the non-diegetic interfaces in Figma with Contrast plugin for check accessibility.

To integrate diegetic visuals, 3D models of real construction site elements such as signs and billboards were directly searched for and text and buttons were added in Unity. Before applying the UI elements, a Figma mockup was created to test the accessibility of the various elements.

Building the task mechanics of the two scenarios

Two distinct scenarios were created, one low-fidelity and one high-fidelity. These prototypes contrast in displays and interactions, with differences in realism and modalities.

Figure 6-11: Low environment.

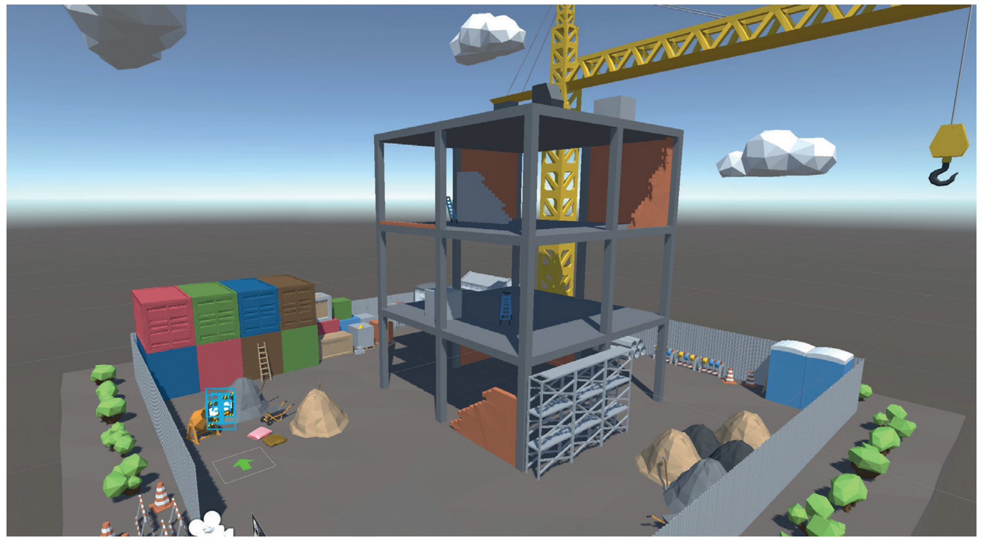


Figure 6-11: High-fidelity environment.

The first step involved incorporating the XR Interaction Toolkit library components into low and high-fidelity versions, specifically the XR Origin and the Locomotion System elements. Continuous turn and continuous move locomotion were integrated by referencing the controller bindings and actions in the Input System. The tutorial at the beginning of the experience explained the available movement modes and interaction options.

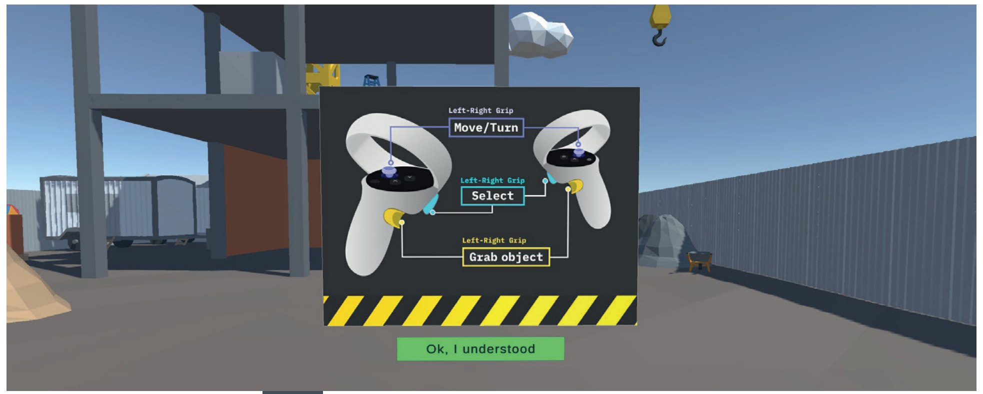


Figure 6-12: Tutorial in the low and high-fidelity scenarios.

Figure 6-12: Tutorial in the low and high-fidelity scenarios.

It can already be seen from the tutorials, in Figure 6-12, how the two different levels of diegesis have been applied to the two scenarios. The low-fidelity scenario utilises 2D interfaces for interaction, while the high-fidelity incorporates elements that exist in the real context of a construction site. As illustrated in Figure 6-13, the first scenario utilizes non-diegetic elements for orientation, whereas the second scenario relies on diegetic elements such as road signs and construction site signs for orientation.

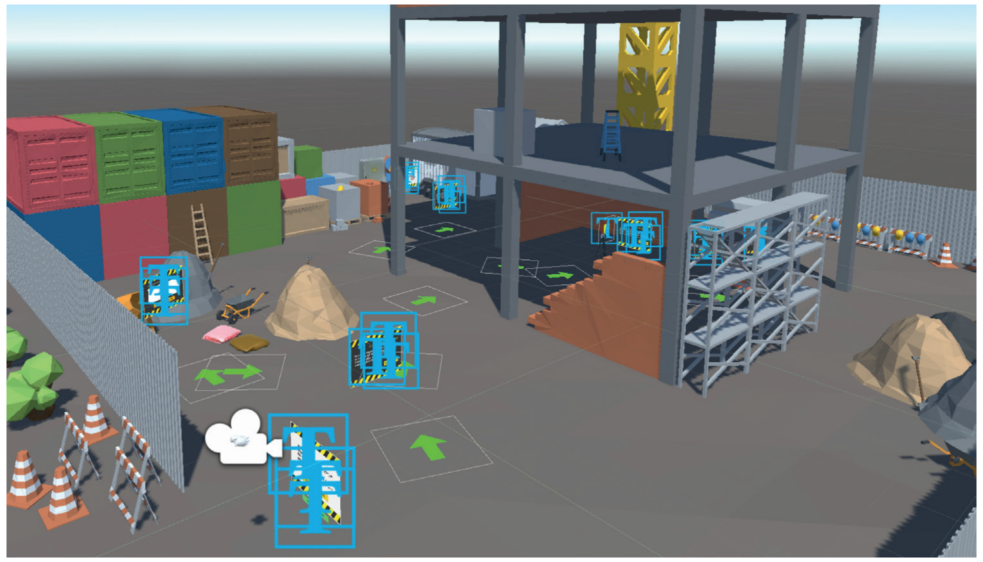


Figure 6-13: Orientation in the scenario based on diegetic and non-diegetic elements.

Figure 6-13: Orientation in the scenario based on diegetic and non-diegetic elements.

Welcome and instructions

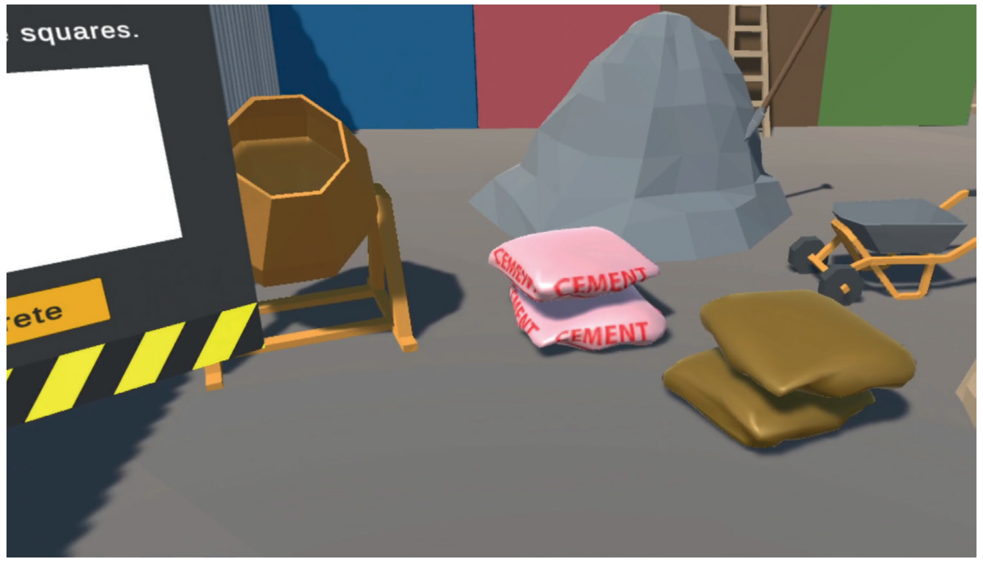
Following fundamental guidelines are presented to direct the user's attention towards following the signs and accomplishing the three designated tasks. To avoid creating too much disparity between the two scenarios and thereby affecting the experiment's outcomes, the instructions and tasks are as similar as possible in their presentation and word formulation.

Figures 6-14: Initial instructions given to the user in the two scenarios.

First task: Create the concrete

The initial task involves producing concrete. In the low-fidelity scenario, this task is presented via the first interface that summarized the information related to the task. In the subsequent interface, the user is able to add two bags, one of cement and one of sand. Following this, the user is prompted to press the button to create the concrete.

Figures 6-15: Use of interfaces to create concrete in the low-fidelity scenario.



In the high-fidelity scenario, a construction site sign outlines the necessary steps to be executed, as shown in Figure 6-16. The user is required to perform a physical interaction by grabbing the shovel, using it to scoop up the concrete pile and then the sand, and transferring the materials to the concrete mixer. Upon inserting a pile of sand and a pile of cement, the machine is activated.

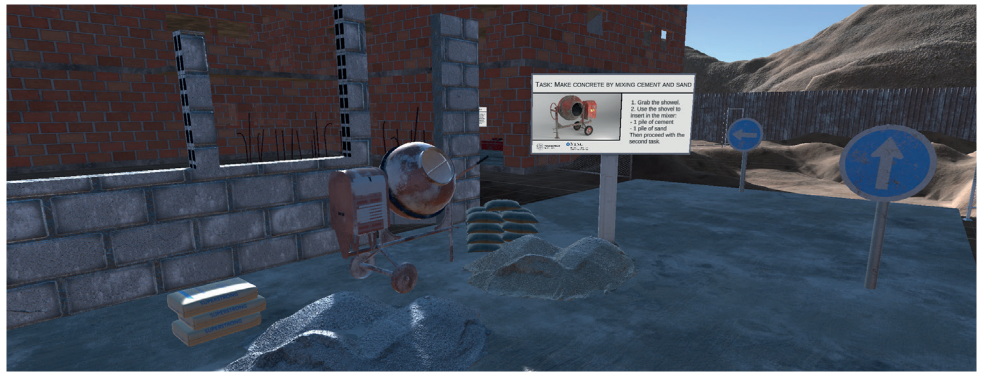


Figure 6-16: Direct interaction with objects to create concrete in the high-fidelity scenario.

Figure 6-16: Direct interaction with objects to create concrete in the high-fidelity scenario.

C# scripts were utilised in both scenarios. In the low-fidelity scenario, the bag is attached to the interface when inserted into the square's box collider achieved by using socket interactors. In the high-fidelity scenario, activation functions are triggered when the shovel object collide with to the box colliders of the piles or the concrete mixer, as shown in Figure 5-16. The feedback given to the user in the first scenario is that the object remains attached in the interface and that once the button is pressed, the interface disappears, and the new wayfinding leading to the second task appears. In the second scenario, the activation of the concrete mixer produces white smoke, indicating to the user that the task has been completed, as shown in Figure 6-18.

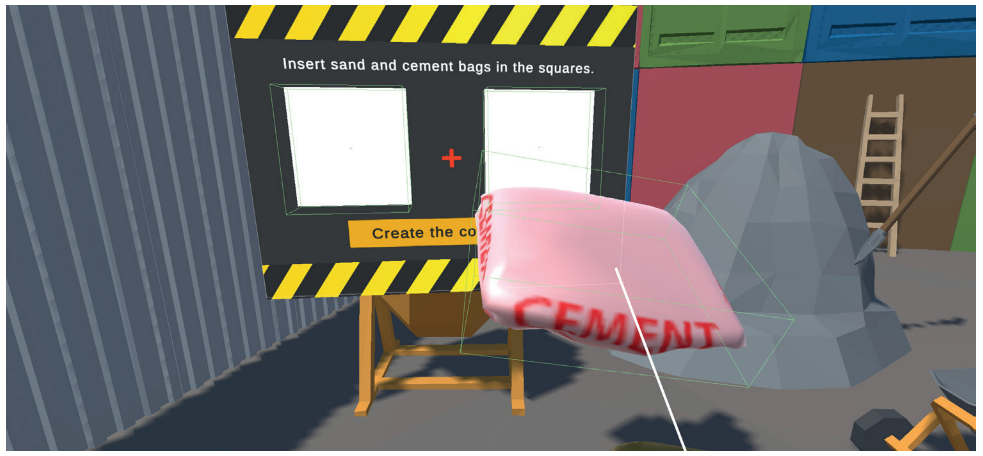


Figure 6-16: The direct interaction with objects to create concrete in the HF scenario.

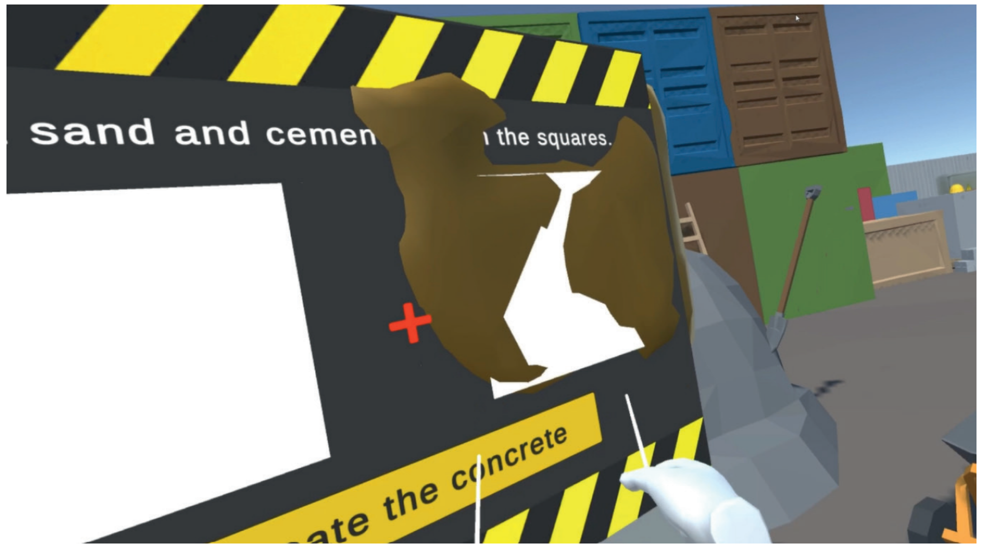
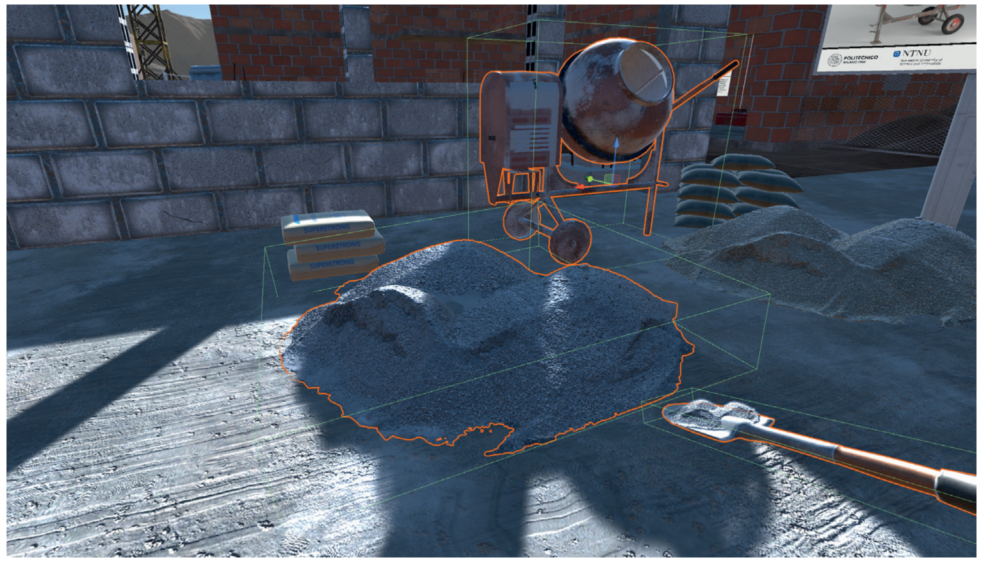
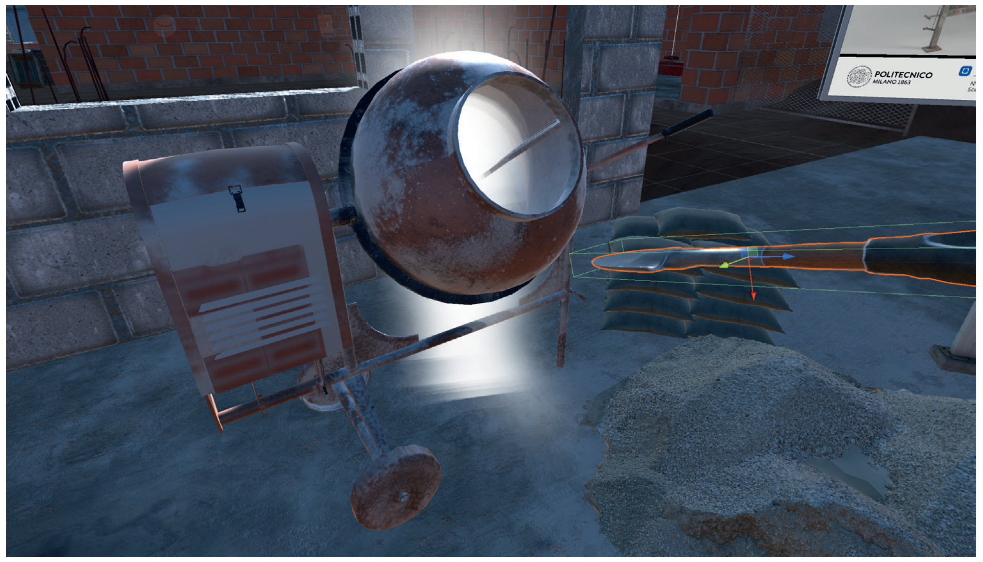


Figure 6-17: Collider boxes to trigger the event of the bag remain attached.



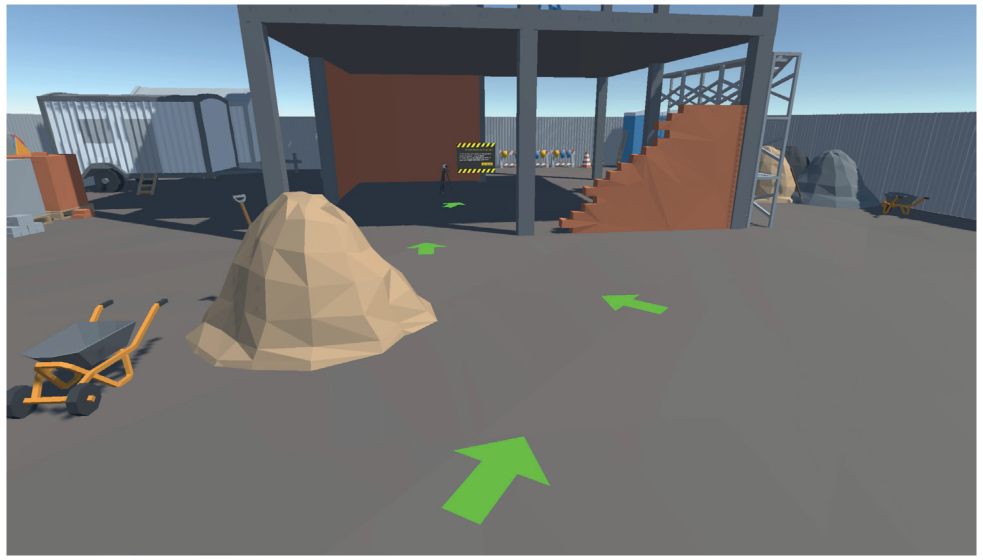
Figures 6-18: Collider boxes to trigger the particle system and give feedback to the user.



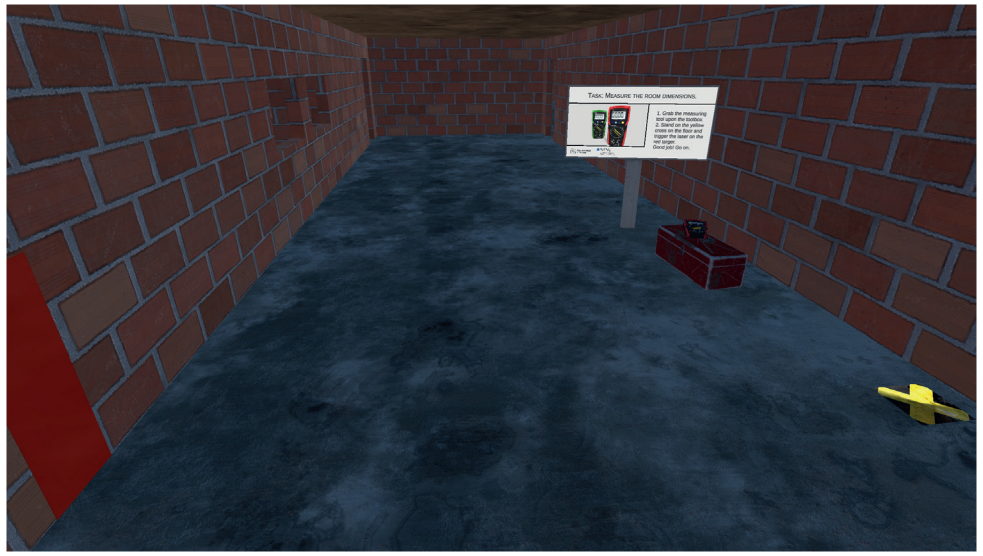
Second task: Measure room dimensions

The second task involves measuring the dimensions of a room. In the low-fidelity scenario, in Figure 6-19, the user accomplishes this by pressing a button located on the opposite side of the room. Initially, the user is presented with a screen describing the task and a tool commonly used for measuring, a laser level. Subsequently, the user is guided to a red circle on the floor where they need to activate a yellow button to measure the length of the room.

Figure 6-19: User indications to accomplish the task in the low-fidelity scenario.

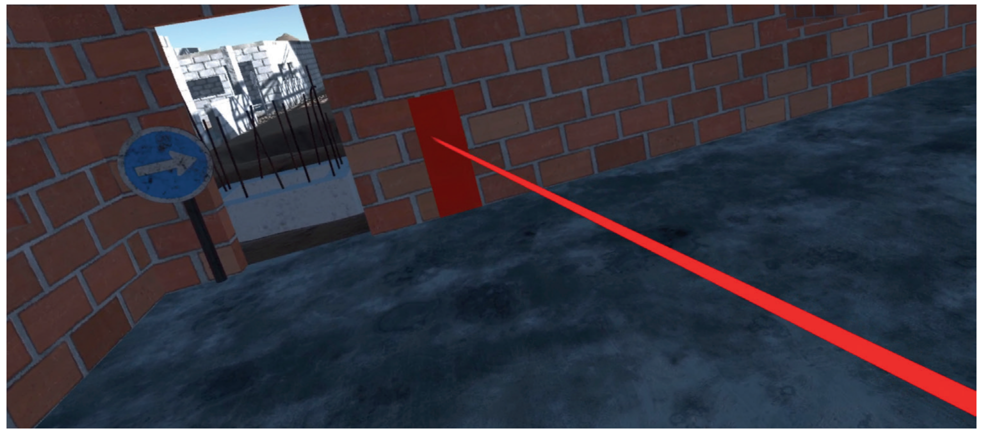


In the high-fidelity scenario, in Figure 6-20, the task is accomplished through direct interaction with a laser meter. The user is asked to hold the device and stand on a cross marked on the floor. From there, the user has to direct the laser towards a line on the opposite wall. Upon reaching the line, the laser is triggered and activated.



Figures 6-20: Using direct interaction with a laser tool to accomplish the task in the high-fidelity scenario.

In the low-fidelity scenario, on the left side of Figure 6-20, the feedback indicating the completion of the task involves the appearance of an interface that displays the length measurements. Additionally, the interface guides the user to proceed to the next task through appropriate wayfinding instructions. In the high-fidelity scenario, on the right side of Figure 6-21, triggering the laser indicates that the task has been successfully completed. Hence, the user should automatically understand that they have accomplished the task.



Figures 6-21: Feedback that the second task has been completed.

Third task: Fix the electrical wire

The third and last task concerns repairing an electrical wire in an electricity box. In the low-fidelity scenario, in Figure 5-21, similar to the previous tasks, the interaction occurs only through interfaces. The user is presented with the problem and given a description of how it is typically resolved. The task is then accomplished by using a button.

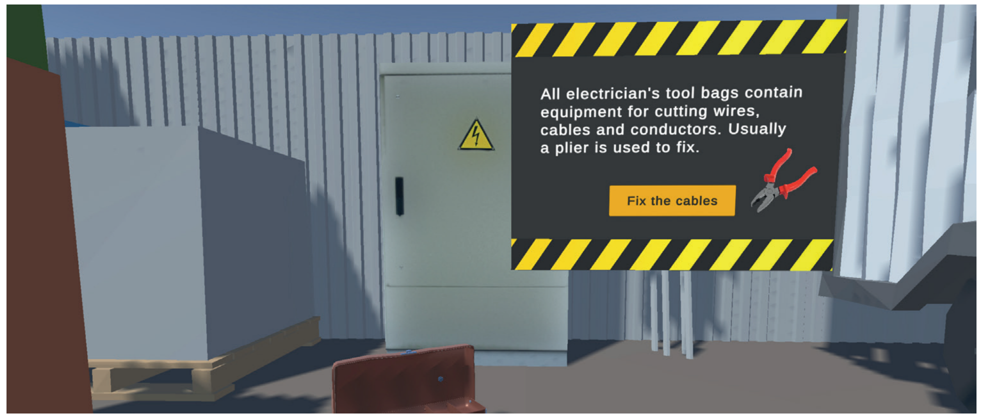


Figure 6-22: Fixing a wire through the interface in the low-fidelity scenario.

In the high-fidelity scenario, in Figure 6-23, the task is still solved by direct action. The user is asked to grab a plier and use it to fix the cable. Additionally, a C# script is utilised in which the particle system generating sparks is deactivated when the pliers move across the space of the box collider of the cable to be adjusted.

Figures 6-23: Fixing an electric cable with a plier in the high-fidelity scenario.

Usability testing

At the end of the development of the first iteration of the prototypes, a usability test was carried out with six users with VR experience, amongst them students studying game development and interaction designers. This test only provided insight about the understanding of the task instructions and interactions of the experience.

Observation and feedback

What was observed and collected from the feedback were various usability problems in the low-poly scenario. Some props played an active role in performing and completing some tasks. For example, in the first task, there were more bags than were needed, and some users realised they had to put in more. In the second task, the laser was in the shape of a gun and was resting on a cube which looked like it should make it ready to be grabbed. All these excess elements were confusing to the user and were therefore eliminated in the second iteration phase of the prototype presented later.

Figure 6-24: Usability testing first iteration.

Second prototyping iteration

Following usability testing, changes were made, especially in the low poly scenario where elements that were confusing were removed.

LF: Changes in the first task

In the first task, shown in Figure 6-25, in order to increase understanding of what has to be performed, the extra bags of material were removed, leaving only the two that were to be inserted into the interface.

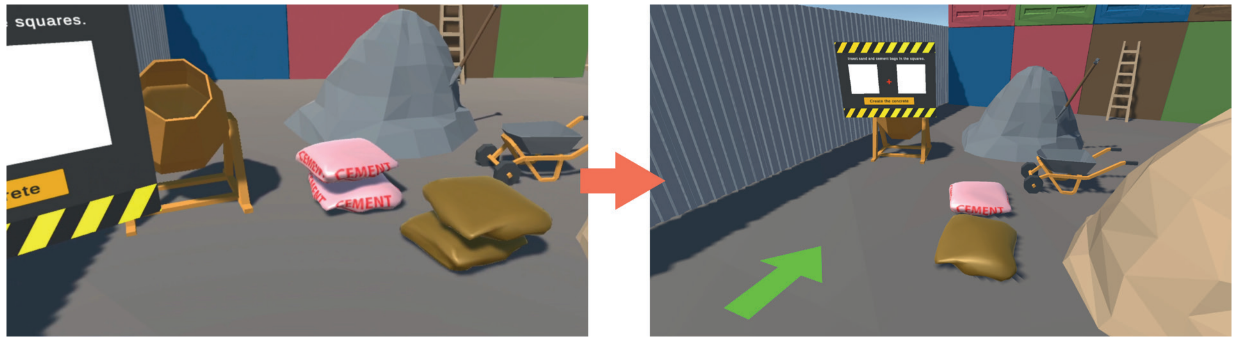


Figure 6-25: Extra elements removed and the interface moved in front of the mixer to prevent confusion.

The interface was moved in front of the concrete mixer because some users thought that the bags had to be placed inside the object. A coloured border, as can be seen in Figure 5-25, was added at the moment the bag hits the interface to let the user know that they have to release the object and that it will be attached.

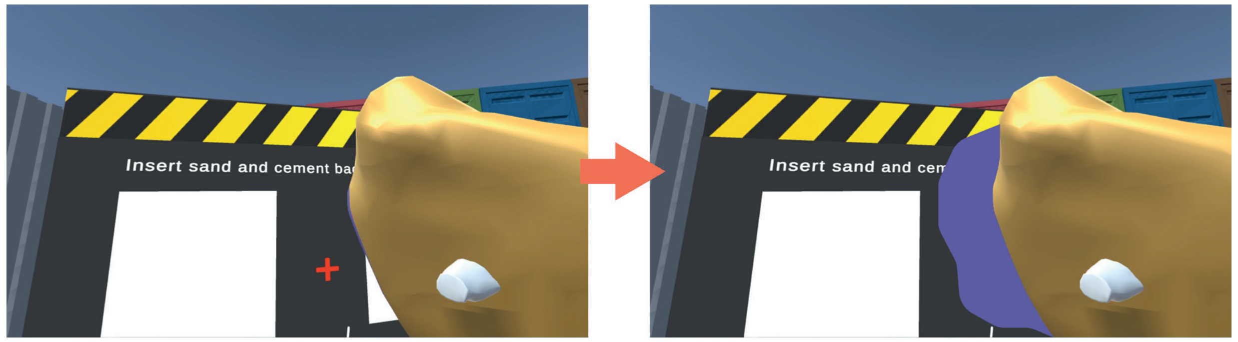
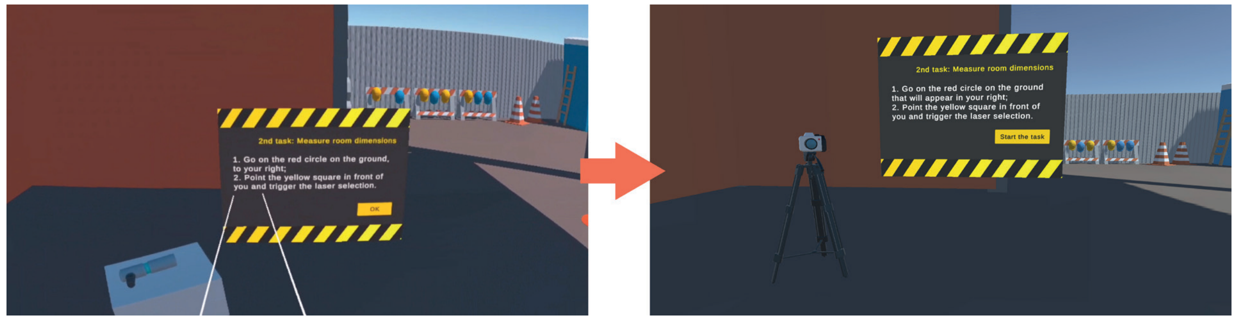


Figure 6-26: Visual elements added to give more feedback.

LF: Changes in the second task

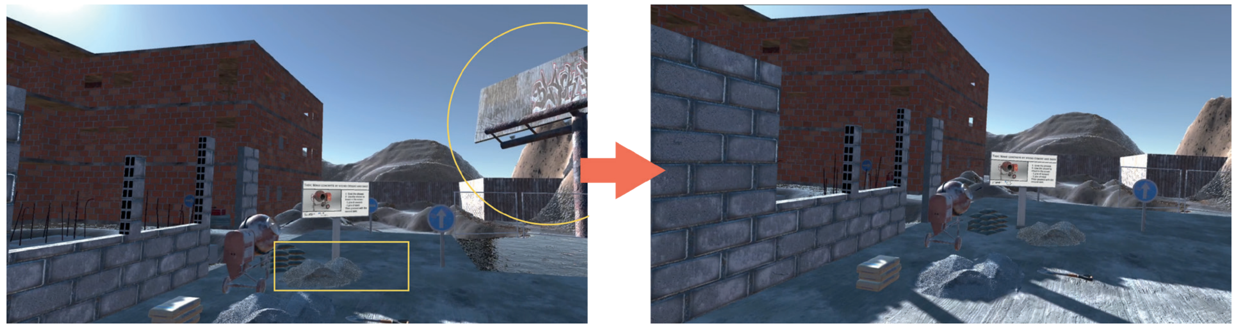
In the second task, in Figure 6-27, the laser gun, which appeared to users as an object to be picked up and used, was removed, and instead a tripod with a laser level was inserted, positioned in such a way that it did not appear to be an object with an active use.



HF: Changes in the first task

Changes were made to the high-fidelity scenario, mainly in the wording of the task instructions. In addition, as can be seen in Figure 6-28, in the first task, the large billboard in the background was removed to avoid confusion, and the sand pile was moved away from the mixer to prevent errors.

Figure 6-27: Change the laser positioned on a cube to a laser level to avoid confusion.



During the usability test was observed that users, when near the mixer with the shovel, inadvertently bumped into the box collider, triggering the script.

Figure 6-28: Billboard removed and pile of sand moved.

HF: Changes in the second task

In the second task, the information was removed from the measurement tool, as it was confusing for the user who thought to press buttons or read important information. The user was thus able to focus on interacting with the tool and possible movements to be performed, as can be seen in Figure 6-30.

Figure 6-29: Information was removed from the measurement tool to avoid confusion.

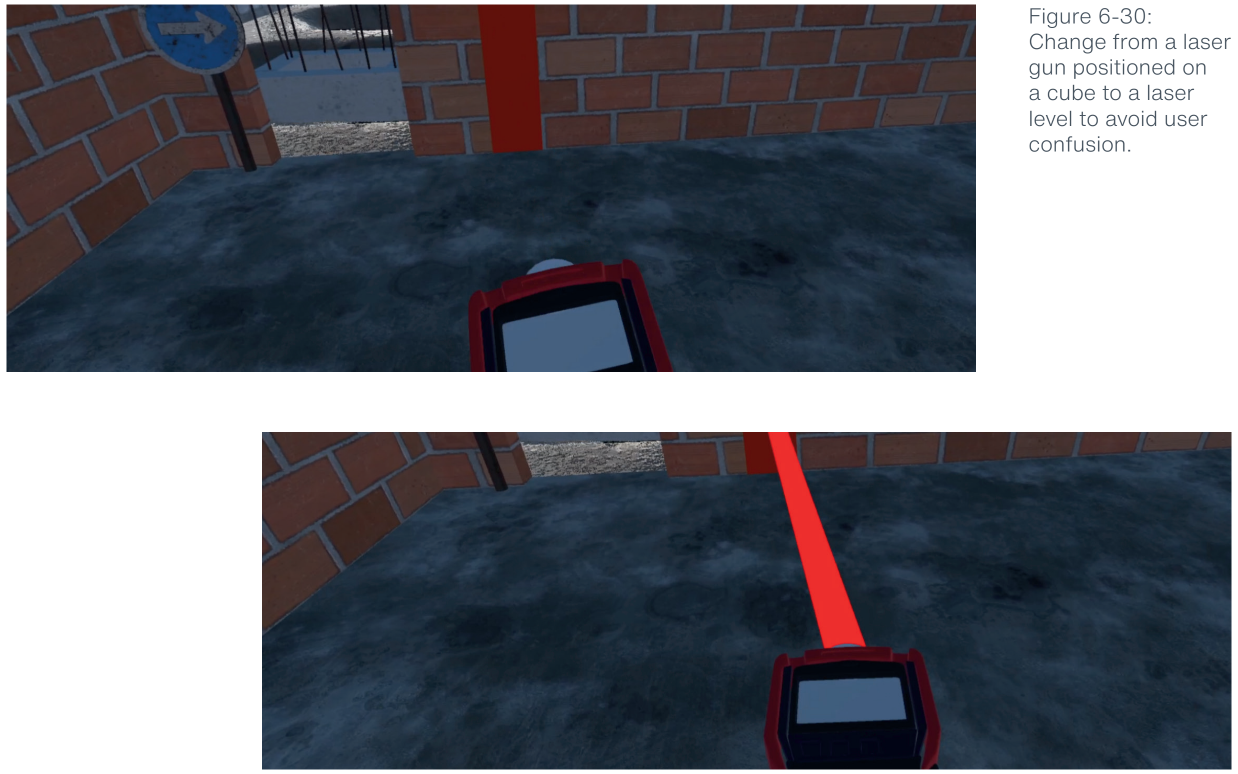


Figure 6-30: Change from a laser gun positioned on a cube to a laser level to avoid user confusion.

HF: Changes in the third task

In the third task, the particle system effect was amplified since some users had not noticed the animation, and therefore, had not realized when the task was completed. This helped to better identify task feedback.

Figure 6-31: Enhancement of the animation provided by the particle system.

Overall, the changes made were driven by reasons of accessibility, understanding of the information and avoidance of confusion. I cambiamenti effettuati hanno permesso agli user di avere una performance più prestante e immediata, senza confusioni riguardo le task da compiere. Il secondo prototipo è risultato più fluido e intuitivo, permettendo così di passare alla fase testing, presentata nel capitolo successivo 6 Testing and results.

07

Testing and results

The methodology and procedures employed in the experiment are detailed in this chapter, followed by an in-depth explanation and analysis of the resulting data.

Material and method

This particular section provides a detailed description of the participants who took part in the experiment, as well as the materials that were utilized throughout the study.

Participants

Fourteen participants, consisting of 6 identifying as female and 8 identifying as male, aged between 18 and 23 years (with an average age of 20.5), were voluntarily recruited from the first year of the Civil and Environmental Engineering bachelor's course at NTNU. The selection was made because of the participant's interest in the construction environment and their lack of direct experience in the field, which was a prerequisite to avoid any potential influence on the test results. None of the participants declared themselves to be VR experts, with 71.4% stating that they were novices and 28.6% stating they had limited experience in using VR. The VR experiences were designed to allow the participants to grasp objects with both hands, hence eliminating the need to select participants based on their dominant hand.

Material

In order to conduct the experiment, two distinct immersive VR scenarios were utilized, one of low-fidelity and the other high-fidelity, both developed utilizing Unity software. The Oculus Quest 2 VR device and a computer were utilized, with a 1.5m long USB type C cable connecting them. To record the ongoing performance, the OBS video recording software was employed to capture the computer screen, while the SideQuest platform was utilized for screencasting the VR environment. For the post-experience questionnaire, Google Forms software was utilized, with users completing the survey immediately after their experience. The survey consisted mainly of multiple-choice questions, where users rated their agreement with the proposed statements on a scale from 1 to 5. The post-two weeks' online survey included a primary open-ended question, as well as two sections containing three multiple-choice questions each.

Procedure

The experiment was conducted over the course of two days, during which two different locations were utilized to gather data.The first location, shown in Figure 7-1, was a 4m2 room situated close to the classrooms of the Civil and Environmental Engineering Department of NTNU. The second location, displayed in Figure 7-2, was located inside the VR Lab of NTNU, which had an area of 3m2. To accommodate participants who were unable to visit the

lab, the low-fidelity prototype test was administered in the nearby room, which only required the use of the Oculus Quest 2. Conversely, the high-fidelity scenario was tested in the lab due to the more complex and computationally demanding scene, necessitating the use of a more powerful computer. To ensure that participants were not distracted by external noise, both rooms were soundproofed and isolated. By minimizing disturbances, the participants were able to fully concentrate on the experience being tested, thereby improving the reliability and validity of the data collected.

Figure 7-1: Testing the low-fidelity prototypes.

Figure 7-2: Testing the high-fidelity prototypes in the VR Lab.

Introductory phase. The introductory phase of the experiment involved a controlled process in which users were asked to enter the room individually to avoid influencing performance. Each session lasted a maximum of 15 minutes and was introduced by a brief explanation of the thesis project, followed by the delivery of consent forms. They were also provided with necessary information regarding the use of the device, such as instructions on how to operate the main commands and were advised to refrain from asking questions during the test. Next, the users were assisted in wearing the HMD and were asked about any usability problems with the device, such as blurred vision or discomfort due to incorrect positioning of the HMD. Once the recording started with the OBS program, the test began.

Familiarization and tutorial. After the introductory phase, despite the brief verbal introduction to the main commands received shortly before, the experience started from a non-diegetic interface, shown in Figure 7-3, or a diegetic board, shown in Figure 6-4, containing a tutorial with information on the trigger placement on the controllers. This allowed users to become familiar with the VR environment and the necessary commands before starting the experiment. The user had the space and opportunity to look around and enjoy the view of the environment before focusing on the command information. This phase lasted an average of 1-2 minutes.

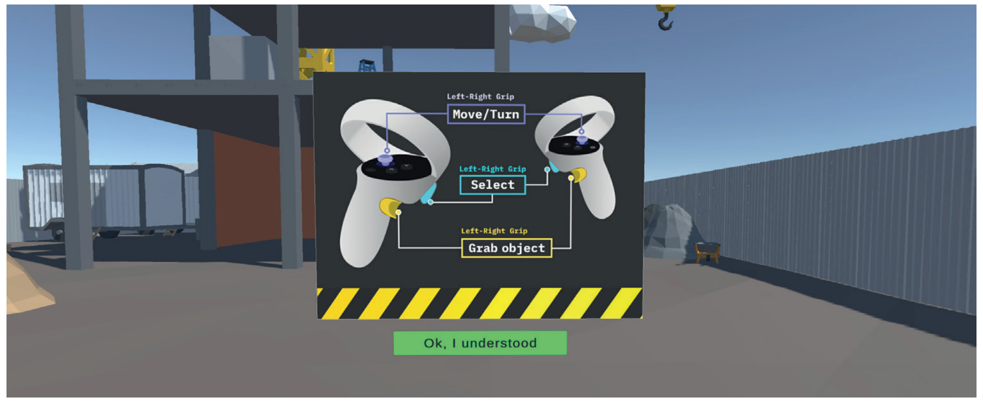
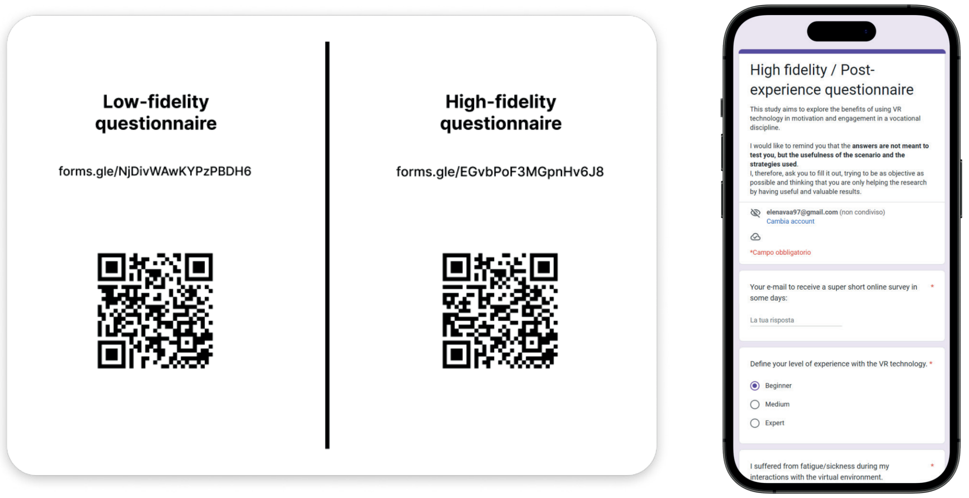


Figure 7-3: Tutorial in the low-fidelity scenario.

Figure 7-4: Tutorial in the high-fidelity scenario.

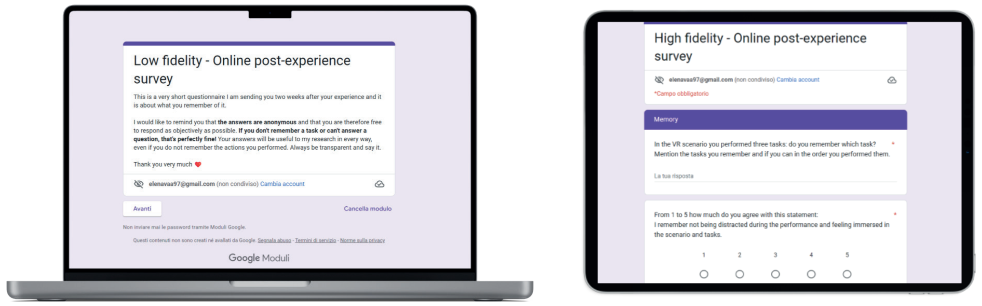
Experimental phase. The experimental phase involved completing all three required tasks using the interfaces provided in the low-fidelity scenario and the diegetic signs in the high-fidelity scenario. This phase lasted an average of 7 to 10 minutes.

Post-experimental phase. After the completion of the experiment, participants were asked to scan a QR code, shown in Figure 7-5, with a questionnaire to measure their cognitive engagement in terms of immersion, presence and flow, perceived usability, and diegesis. Participants were asked to provide first their email addresses, to receive a post-two weeks survey, and then to rate their perception on 22 sentences on a Linkert scale from 1 to 5. The user had to express their level of agreement with each sentence.



Figures 7-5: QR code and link to questionnaires.

Post-two weeks online survey. Two weeks after the experiment, participants received a post-experience memory survey in which they were asked to recall what they remembered about the tasks performed during the VR experience. This survey included open-ended questions and multiple-choice options to gather a comprehensive understanding of their experience.



Figures 7-6: Survey post-memory on the LF scenario.

Measures

This section provides an overview of the measured parameters and indicators essential in interpreting the study results. These parameters were chosen based on their relevance to the research questions and objectives.

Performance

To evaluate participant performance, a combination of observation and time measurement techniques was employed. Each participant was recorded throughout the entire VR experience, allowing for an assessment of their overall performance and individual task execution and timing. During the observation period, notes were taken on any errors made, comments made by the participant, and any moments of difficulty experienced. Each task was also timed using a timer to further quantify performance. This combination of qualitative and quantitative data allowed for a more comprehensive evaluation of participant performance.

Perception and cognition: immersion, presence and flow

The data for perception and cognition parameters such as immersion, presence, and flow were extracted from the post-experience questionnaire. The questionnaire was based on the subjective VRLEQ scale [80], which is based on the SUS scale [53] and the GEQ [77]. Participants were asked to rate their experience on a 5-point Linkert scale (1=strongly disagree, 2=somewhat disagree, 3=neither agree nor disagree, 4=somewhat agree, 5=strongly agree). This allowed for a quantitative assessment of the participant's subjective experience during the VR tasks.

Figure 7-8: Table with perception and cognition questions from the post-experience questionnaire.

#	Statement	Dimension
1.	I found it tiresome or challenging.	Flow, Cognitive Load
2.	I felt successful.	Flow
3.	I was interested in the tasks.	Immersion
4.	I found it impressive.	Immersion
5.	I felt bored.	Flow
6.	I felt confused.	Flow
7.	I forgot about the outside world around me (external).	Presence
8.	I felt transported to a construction site.	Immersion
9.	I enjoyed being in this virtual environment.	Flow
10.	I lost track of the time while I was in the experience.	Presence, Flow

The post-experience questionnaire, shown in Figure 7-8, was designed to gather subjective feedback from participants on their experience in the VR environment. The VRLEQ scale was chosen because it is a widely used and validated measure of presence and immersion in virtual environments. Using a 5-point Linkert scale, participants could express their level of agreement or disagreement with each statement, providing a quantitative measure of their subjective experience.

Additionally, cognitive involvement was also evaluated in a survey, shown in Figure 7-9, sent to participants two weeks later, where they were asked to rate on a scale of 1 to 5 how much they remembered feeling immersed in the scenario.

Figure 7-9: Table with immersion and presence question in the survey sent after two weeks.

Type of question	Question	Dimension
	1st section	
Linear scale	From 1 to 5, how much do you agree with this statement: I remember not being distracted during the performance and feeling immersed in the scenario and tasks.	Immersion, Presence

The aim was to provide valuable insights into the long-term impact of the VR experience on participants. Measuring cognitive involvement both immediately after the VR experience and at a later point in time can help to gain a more comprehensive understanding of the impact of the VR experience on participants' cognitive and emotional states.

Usability, Interaction and Diegesis

Usability, interaction, and diegesis were evaluated through observation and specific questions in the post-experience questionnaire, related to the user's perception of interaction and experience in terms of intuitiveness. Observation involved watching and recording users' interactions to understand better how they navigate the virtual space, interact with objects, and react to various stimuli. Meanwhile the post-experience questionnaire was based on the subjective VRLEQ scale [80], which is based on the SUS scale [53] and the GEQ [77]. Participants were asked to rate their experience on a 5-point Likert scale (1=strongly disagree, 2=somewhat disagree, 3=neutral, 4=somewhat agree, 5=strongly agree).

Figure 7-10: Table with questions about usability, interaction and diegesis from the post-experience questionnaire.

#	Statement	Dimension
11.	I thought the navigation was easy to use.	Usability, Cognitive Load
12.	Was always clear for me what to do.	Usability, Cognitive Load
13.	The VR environment was responsive to my actions.	Usability
14.	I felt confident selecting and grabbing objects.	Usability, IF
15.	I understood when a task finished.	Usability
16.	The behaviour of the objects in the virtual.	Usability, IF
17.	I've felt to need external help to deal with some tasks.	Usability, Cognitive Load
18.	I think the interaction was intuitive and natural.	Usability, IF, Diegesis
19.	I believe that the graphics and the environment were appropriate for the construction field and helped me to immerse myself in the environment atmosphere.	Diegesis
20.	The elements that told me how to perform the tasks did not make me feel that I was in a virtual environment.	Diegesis
21.	I found that elements of the scene were suitable to give a taste of what a construction site is like.	Diegesis
22.	I think the realism of the environment was enough.	Diegesis, IF, DF
23.	I think the interfaces and objects appeared to be authentic and consistent with the environment.	Diegesis

Furthermore, usability was also evaluated through the post-two weeks survey sent to participants, as shown in Figure 7-11. In addition to ask them what they remembered about the tasks they performed during the VR experience, was taken the opportunity to ask them if they experienced any confusion while performing or after performing a task.

Figure 7-11: Table with questions about usability in the survey sent after two weeks on memory.

Type of question	Question	Dimension
	2nd section	
Paragraph	Do you remember having an easy understanding of what to do in this task or were you a little confused before or after performing the task?	Usability
	3rd section	
Paragraph	Do you remember having an easy understanding of what to do in this task or were you a little confused before or after performing the task?	Usability
	4th section	
Paragraph	Do you remember having an easy understanding of what to do in this task or were you a little confused before or after performing the task?	Usability

Assessing usability in a post-experience survey can provide valuable insights into how participants interacted with the VR experience. In particular, asking participants about their recall of the tasks performed and whether they experienced confusion can shed light on how usable the experience was. By conducting this survey two weeks after the VR experience, it allows for a more accurate reflection of the long-term usability and user experience.

Memory and knowledge retention

To measure memory and knowledge retention, an online survey was used as an evaluation tool sent to participants two weeks after the experience. Memory and knowledge retention pertains to the process of absorbing and storing information. In general, this entails the assimilation of data and transferring it from short-term memory to long-term memory. The survey consisted of two sections, the first of which included an open-ended question about what users remembered regarding the performed tasks. The second section was devoted to each task and included specific multiple-choice questions and a short-answer question about how the user felt while performing the task. Prior to answering the questions, users were reminded to be impartial and open in their responses. The questionnaire responses were gathered anonymously.

Figure 7-12: Table with questions in the survey sent after two weeks on memory.

Type of question	Question	Dimension
1st section		
Paragraph	In the VR scenario you performed some tasks: do you remember which task? Mention the tasks you remember and if you can in the order you performed them.	Memory, Knowledge retention
Linear scale	From 1 to 5, how much do you agree with this statement: I remember not being distracted during the performance and feeling immersed in the scenario and tasks.	Immersion, Presence
2nd section		
Multiple choice	Do you remember being asked to mix sand and cement to create concrete?	Memory, Knowledge retention
Multiple choice	Do you remember using a mixer as a tool to create concrete?	Memory, Knowledge retention
Paragraph	Do you remember having an easy understanding of what to do in this task or were you a little confused before or after performing the task?	Usability
3rd section		
Multiple choice	Do you remember being asked to measure the dimensions of the room?	Memory, Knowledge retention
Multiple choice	Do you remember using a laser tool to measure a room's dimensions?	Memory, Knowledge retention
Paragraph	Do you remember having an easy understanding of what to do in this task or were you a little confused before or after performing the task?	Usability
4th section		
Multiple choice	Do you remember you were asked to fix an electricity cable/ wire?	Memory, Knowledge retention
Multiple choice	Do you remember using pliers to fix the cable?	Memory, Knowledge retention
Paragraph	Do you remember having an easy understanding of what to do in this task or were you a little confused before or after performing the task?	Usability

Knowledge retention is a key factor in learning, and the ability to transfer information from short-term to long-term memory is a crucial component of the learning process. The survey used in this study was designed to capture both open-ended and specific information related to each task performed during the VR experience. By including multiple-choice and short-answer questions, it was possible to comprehensively understand how participants felt during task performance and what they remembered afterwards. It is important to note that the anonymity of the survey allowed participants to provide honest and objective feedback without fear of judgment or bias.

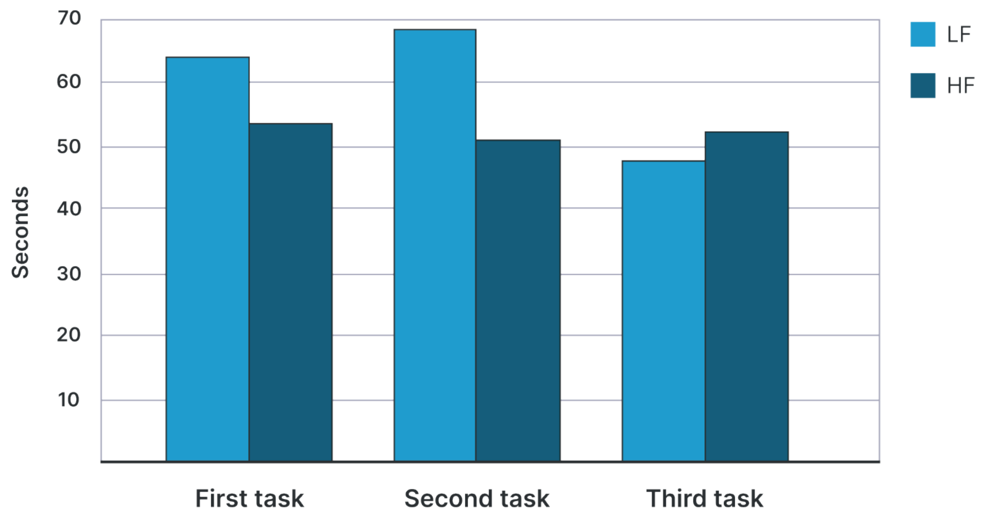
Results

This section contains the results of the measurements detected, collected during the tests, and analyzed after obtaining the post-experience survey sent to participants two weeks later. The results are based on quantitative and qualitative data from the survey responses and the observations made during the VR experience. By analyzing the data, the aim is to gain a better understanding of the usability, interaction, and knowledge retention of the VR experience, which can provide valuable insights for future VR design and development.

Performance

On average, participants took more time to complete the tasks in the LF scenario (average of 181.3 seconds) than in the HF scenario (average of 158 seconds). However, from observation, users took longer to read the text in the non-diegetic interfaces in the LF scenario, but overall there was not much difference in perceived difficulty when observing the user during the test. In the LF scenario, the first task lasted an average of 64.1 seconds, the second task 68.4 seconds, and the third task 48.8 seconds. In the HF scenario, the first task lasted an average of 54.2 seconds, the second task 51.4 seconds, and the third task 52.4 seconds. 42.9% of participants reported experiencing some motion sickness (6 out of 14), while 57.1% reported not experiencing any motion sickness (8 out of 14). None of them had such a strong feeling of motion sickness that they had to abandon the experience, and all participants completed all the tasks.

Figure 7-13: Time differences on the performance of the two scenarios.



Perception and cognition: immersion, presence, flow

The post-experience questionnaire provided data to assess the parameters of perception and cognition, including immersion, presence, and flow. The participants' ratings for immersion were 3.85/5 on average in the LF scenario and 4.14/5 on average in the HF scenario. Presence was rated an average of 3.97/5 in the LF scenario and 4.28/5 in the HF scenario. Finally, flow was rated an average of 3.38/5 in the LF scenario and 3.66/5 in the HF scenario.

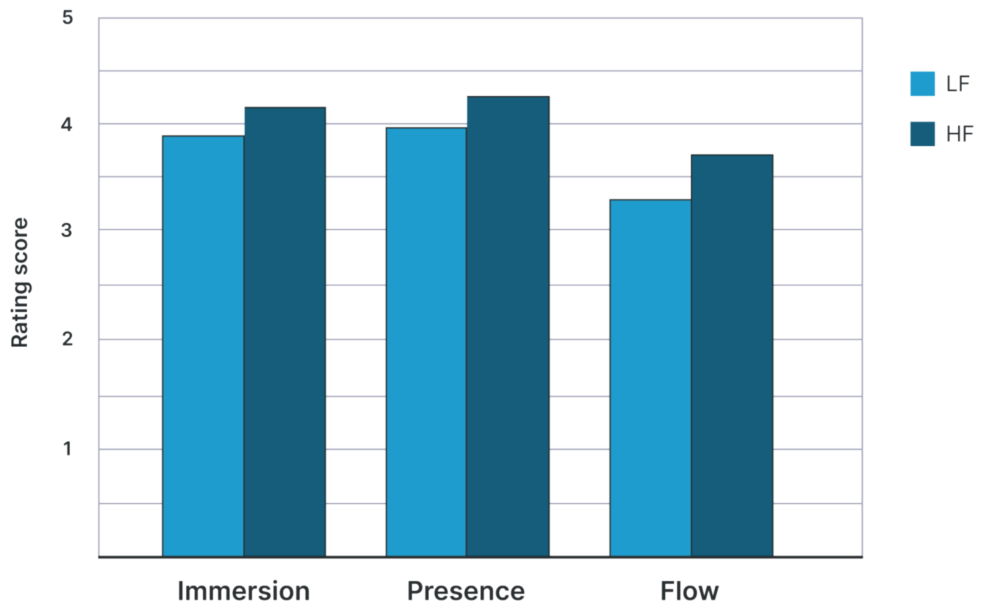


Figure 7-15: Immersion, Presence and Flow perceived by the participants.

According to the survey sent out two weeks later, participants in the LF scenario reported a mean rating of 4/5, indicating that they felt immersed in the scenario and tasks performed. For the HF scenario, participants' ratings were even higher, with an average of 4.42/5.

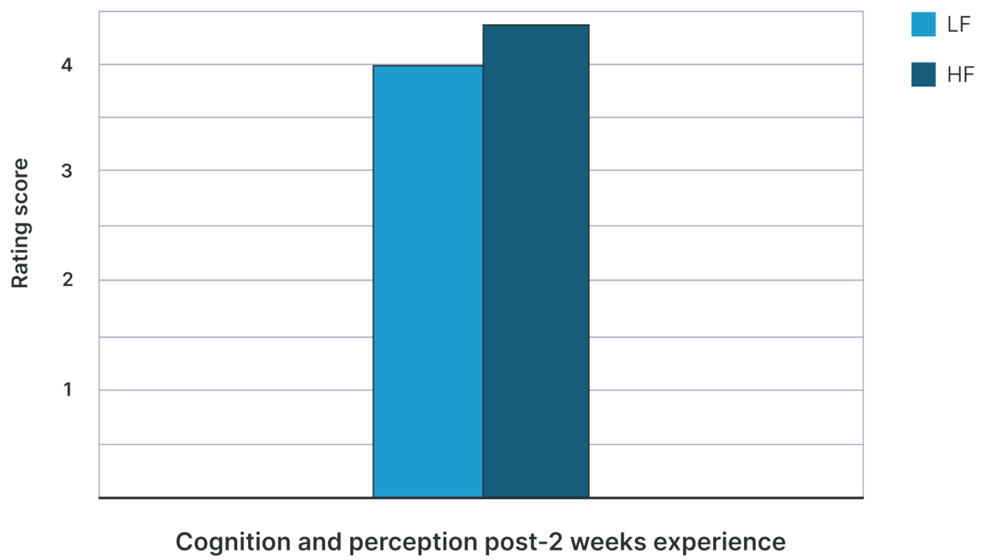
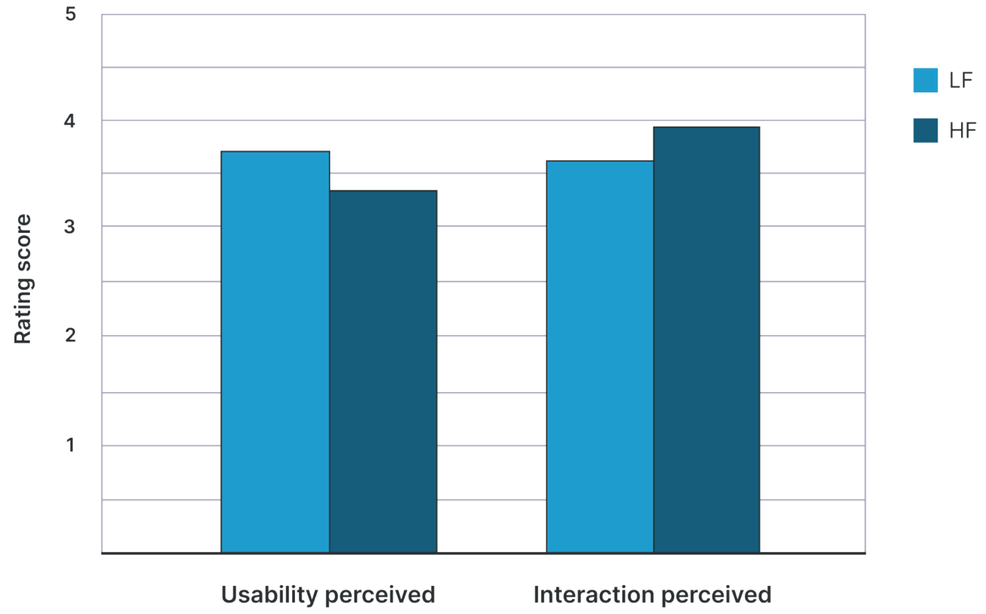


Figure 7-16: Immersion perceived from the participants 2 weeks later.

Usability and interaction

The perceived usability ratings from participants were slightly higher for the LF scenario with an average of 3.75/5, compared to 3.59/5 for the HF scenario. Specifically, the perceived usability was rated 3.67/5 in the LF scenario and 3.41/5 in the HF scenario, while the perceived interaction was rated 3.6/5 in the LF scenario and 3.91/5 in the HF scenario.

Figure 7-17: Usability and interaction fidelity perceived from the questionnaire.



Based on observations and notes taken during the test, it appears that participants in the HF scenario experienced more moments of confusion and disorientation, as they were not always clear when an action was completed and would ask for confirmation. In contrast, participants in the LF scenario completed all the tasks without asking for help or confirmation of what they needed to do. Regarding interaction with interfaces and diegetic elements, the interaction was much more intuitive for participants in the HF scenario than for those in the LF scenario. Participants in the LF scenario often tried to interact with objects they saw instead of the interfaces.

Figure 7-18: Usability perceived from the participants 2 weeks later.

LF

HF

“Yes, it was all clear. Easy.

The task was too easy. It was easy to understand.

Easy task. Only one click and it was over :)

After realising I had to interact with interfaces and not objects, it was all easy.”

“I didn't know when to stop.

I didn't know how to use the tool.

It was clear what to do during the task but not when it was completed.

I wasn't sure when the task was done but just assumed based on the lack of sparkling animation.”

After two weeks from the test, participants of the LF scenario reported that they did not have any issues and understood the tasks, commenting that some of them were even too simple. They said, “Easy task. Only one click and it was over :)” and “Yes, but the task was too easy.” On the other hand, participants of the HF scenario reported on average that they had trouble understanding when the task was complete. They stated, “I didn't know when to stop” and “I wasn't sure when the task was done but just assumed based on the lack of sparkling animation.”

Diegesis

The perceived diegesis by participants in the LF scenario has an average rating of 3.07/5, while for the HF scenario, the average is 4.5/5. Specifically, participants in the LF scenario gave a higher average rating to “I believe that the graphics and the environment were appropriate for the construction field and helped me to immerse myself in the environment atmosphere,” and a lower rating to “I found that elements of the scene were suitable to give a taste of what a construction site is like.”

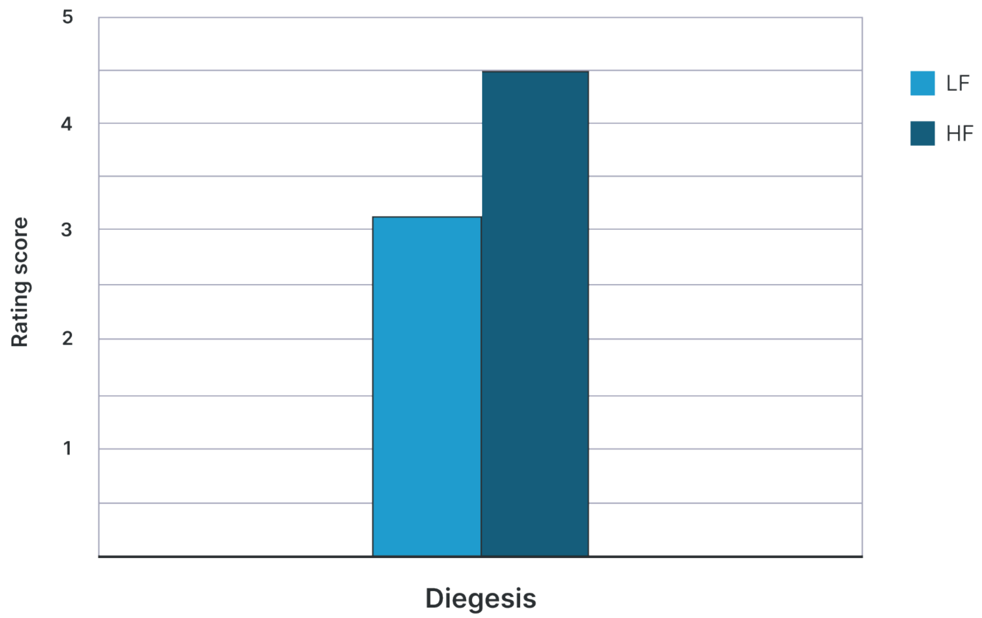


Figure 7-19: Diegesis perceived from the questionnaire.

Memory and knowledge retention

According to the survey conducted two weeks after the experience, it was found that all 14 participants were able to recall the three tasks they performed in order: creating the concrete, measuring the room dimensions, and fixing the cable in the electrical cabin. However, it was noted that some participants in the LF scenario were not able to recall their actions accurately, with some describing the second task as “pointing a laser to a yellow square” instead of recalling that they had measured a wall.

In particular, in the LF scenario:

- In the first task, all 7 participants remembered that they had mixed sand and cement, but only 57.1% (4/7) recalled using a concrete mixer to complete the task.
- In the second task, all 7 participants remembered measuring the dimensions of a room, but only 28.6% (2/7) recalled using a laser level.
- In the third task, all 7 participants remembered completing the action of fixing an electrical cable in a cabin, but only 42.9% (3/7) remembered using pliers to complete the task.

Creating with a concrete mixer: Measuring with a laser tool: Fix the cable with a pliers:

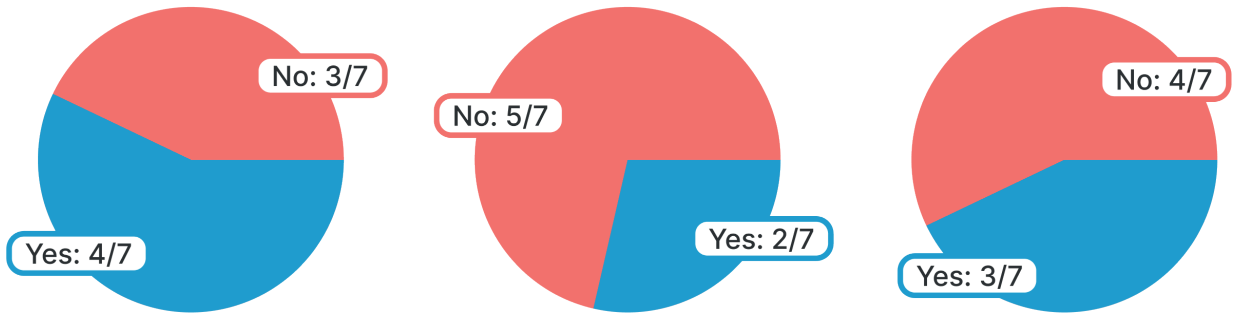


Figure 7-20: Memory about the task performed in the LF scenario collected from the post-2 weeks survey.

Regarding the HF scenario:

- In the first task, 7/7 participants reported remembering mixing sand and cement, and all 7/7 remembered using a concrete mixer as a tool to complete the task.
- In the second task, 7/7 participants reported remembering measuring the dimensions of a room, and only one participant (1/7) stated not remembering using a laser level.
- In the third task, 7/7 participants remembered completing the action of fixing an electrical cable in an electrical cabinet, and all of them remembered using pliers as a tool to complete the task.

Creating with a concrete mixer: Measuring with a laser tool: Fix the cable with a pliers:

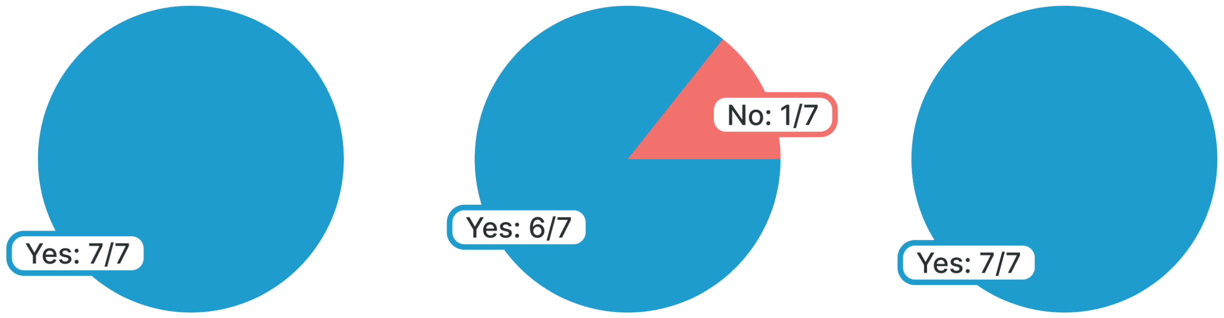


Figure 7-21: Memory about the task performed in the HF scenario collected from the post-2 weeks survey.

As explained in the usability section, in the LF scenario, on average, all participants recalled having a simple and intuitive experience, perhaps even too much so. However, concerning the HF scenario, participants reported that it was not always clear when a task had been completed or not.

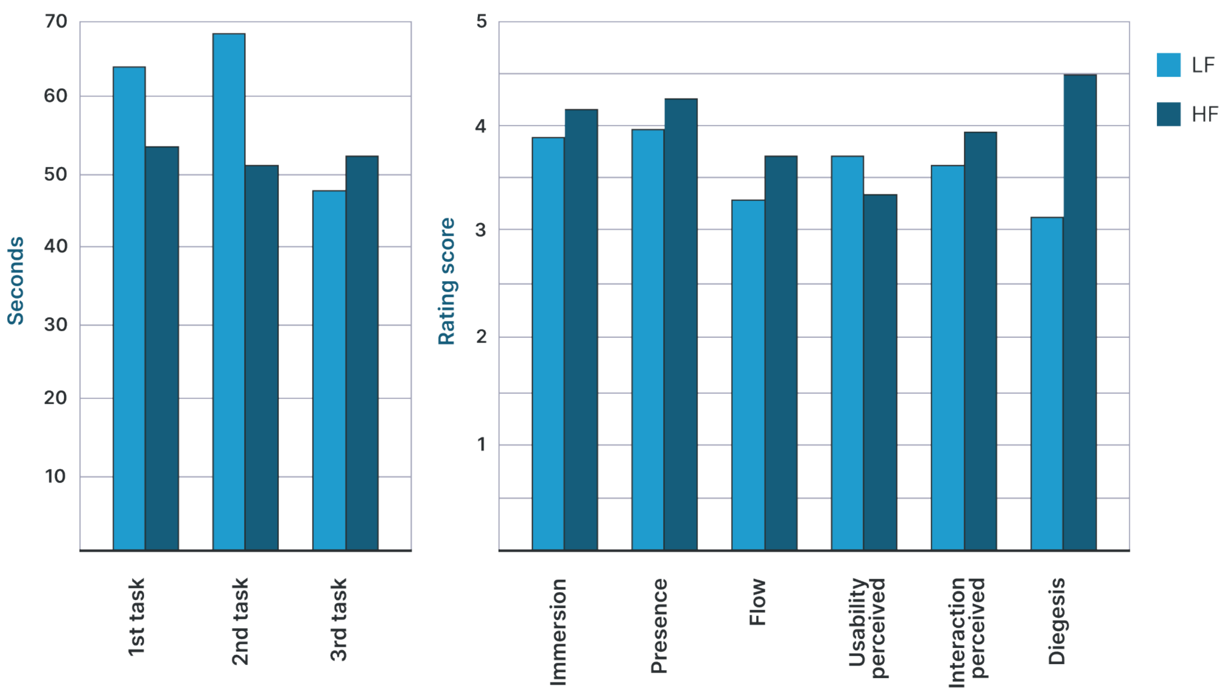
08

Discussion

This section will provide a detailed analysis of the results presented in Chapter 07. By interpreting the data and providing explanations for the findings, the aim is to provide a deeper understanding of the research topic and its implications. This discussion will also serve as a bridge between the results and the final concluding chapter, where meaningful conclusions and future research directions in the field will be suggested.

Discussion of the results

The following section presents a discussion of the outcomes acquired from the VR task performance tests, assessing several aspects such as cognitive and emotional involvement, usability, level of interaction, diegesis, and memory and knowledge retention. The results indicate that, in general, the HF scenario has generated higher scores compared to the LF scenario, primarily in terms of timing, reducing the time taken to accomplish tasks, and the perception of involvement and dissociation from reality. Nonetheless, one significant exception can be seen in the perceived usability, where users have reported a sense of confusion due to the lack of visual feedback after completing the tasks, primarily because of the diegesis concept. The diegesis attempts to make the environment as close to reality as possible to support the narrative flow, leading to a minor setback in usability. Overall, the study provides valuable insights for future VR design and development, emphasizing the importance of balancing diegesis and usability in creating a compelling VR experience.



8-1: Summary of the results of the questionnaire

As displayed in Figure 8-1, the results show that the difference between the two scenarios is not so significant, and both scenarios have achieved a good level of performance, involvement, and perceived usability. Furthermore, both the questionnaires and observations made during the tests showed that users were positive and enthusiastic during the experience of both scenarios. The fact that the majority of the participants, 71,4%, had no prior experience with VR technology may have contributed to their overall excitement and interest in the study.

Performance of the tasks

Regarding performance, the results suggest that the average time to complete the tasks in the LF scenario is longer than the HF scenario. However, the difference is not significant because the user, as observed and noted during the test, took more time to read the tasks in the LF scenario. Only the third task was completed on average in less time, which can be attributed to the fact that in the LF scenario, there was no real interaction but rather an explanation of how to solve the problem, showing some objects that would be useful in the activity.

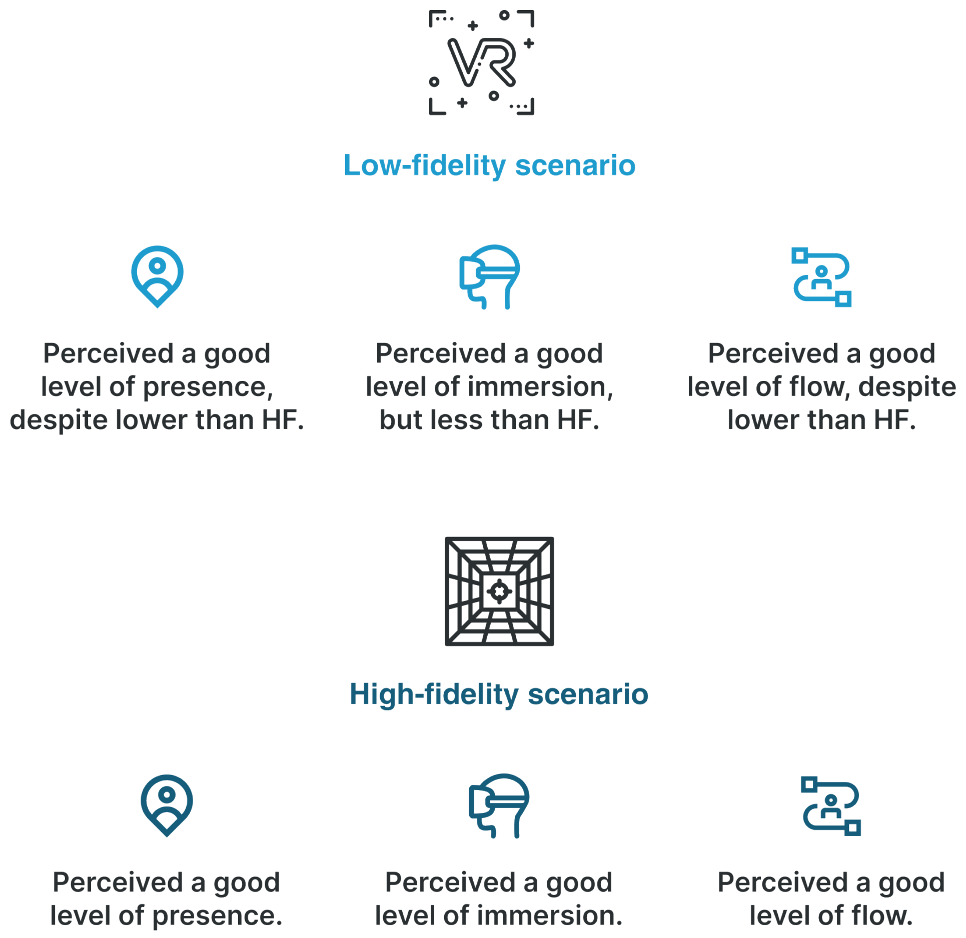
Figure 8-2: Differences in the performance on the two scenarios.

The overall findings suggest that there was no significant difference in the time and effort expended by the participants to complete the tasks in the two distinct settings. In the LF scenario, the participants felt more guided by the interfaces, but they also took longer to read and execute the actions. In contrast, in the HF scenario, the participants felt less guided due to the diegesis concept, which lacked clear visual feedback upon task completion. However, interacting with objects that were closely similar to real life made the actions more intuitive, eliminating the need to concentrate on reading instructions.

Perception and cognition

The results suggest that, as observed in the literature research analyzed in Chapter 03, participants experienced higher levels of perceptual and cognitive engagement in the HF scenario compared to the LF scenario. This finding aligns with the study's hypothesis that higher fidelity would lead to increased immersion and engagement. Nonetheless, it is important to note that the difference in ratings between the two scenarios was not statistically significant, implying that the LF scenario was still effective in providing a sense of immersion and engagement, as shown in Figure 8-3.

Figure 8-3: Differences in the perception and cognition of the two scenarios.



The results of the post-survey conducted two weeks after the study reveal that participants had a positive perception of their immersion level in both scenarios. This finding is significant because it suggests that even with a low-fidelity VR scenario, users can still experience a satisfactory level of immersion, engagement, and presence. Moreover, since the tasks in both scenarios were similar and not particularly complex, the level of flow was also reported as high due to the limited difficulties encountered in completing the required activities.

Usability and interaction

In terms of usability and interaction, the data collected from the questionnaire and observations suggest that users found it much more intuitive to directly interact with realistic objects in the construction site in the HF scenario, while interacting with interfaces to manipulate the virtual environment in the LF scenario was less intuitive, as synthesised in Figure 8-4. However, the interfaces in the LF scenario provided greater clarity for users regarding feedback on task completion. In the HF scenario, this feedback was visually presented in a diegetic form through the activation or deactivation of animations. However, if users did not pay immediate attention to these effects, they

would continue to perform the same task in search of some kind of approval feedback.

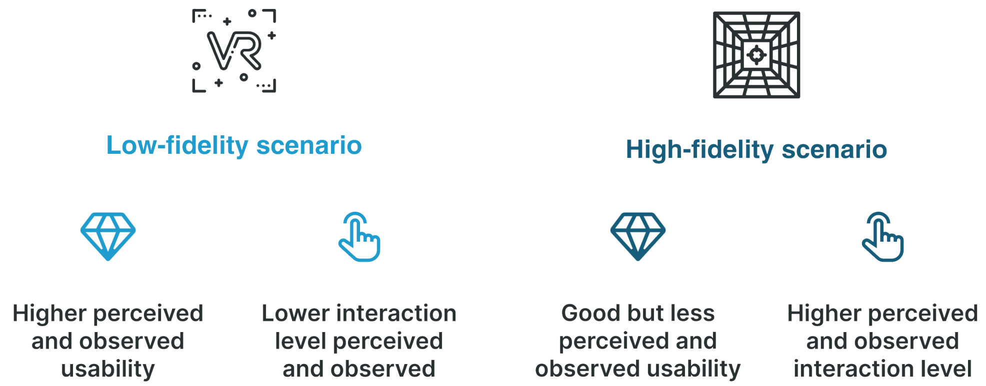


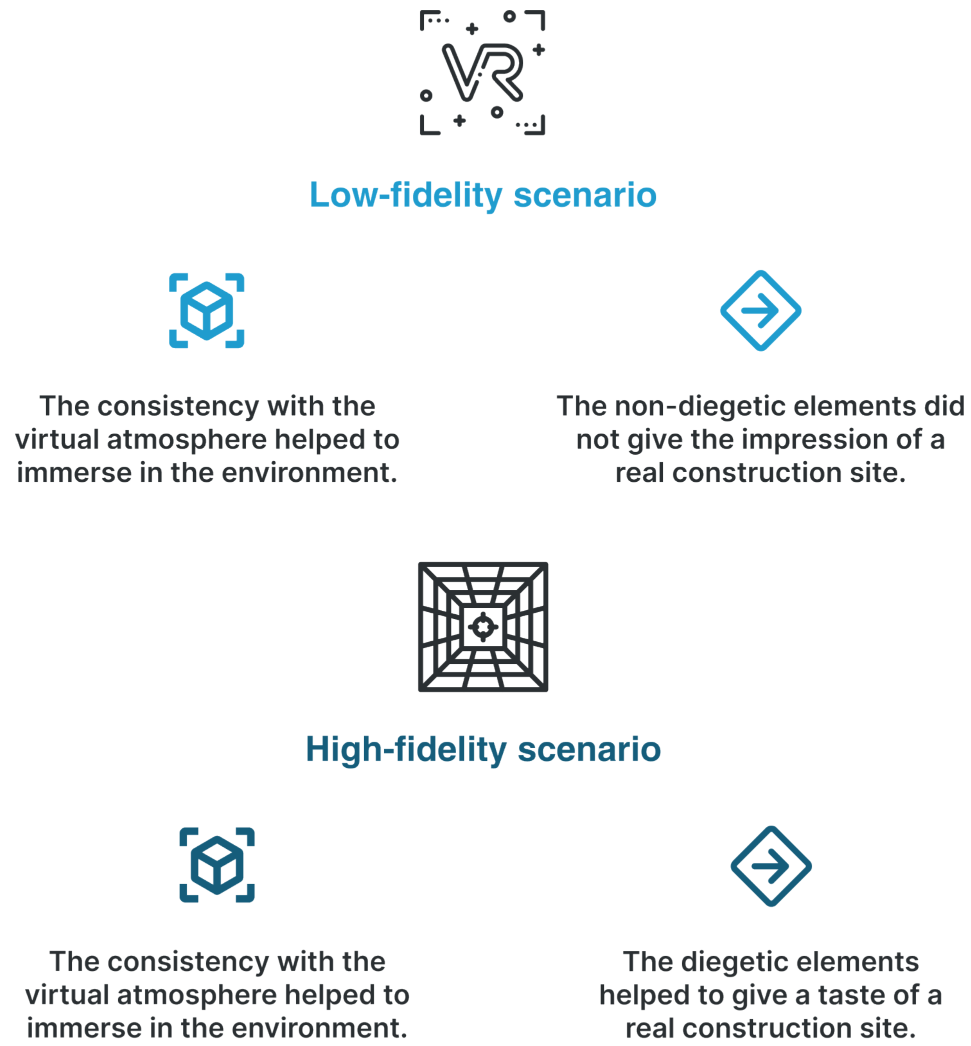
Figure 8-4: Differences in usability and interaction on the two scenarios.

Despite some differences in perceived usability and interaction between the LF and HF scenarios, the overall ratings were relatively close and indicate a reasonable level of usability in both cases. It is important to note that the tasks used in the study were relatively simple, and more complex tasks may lead to different results in terms of perceived usability and interaction. Overall, the difference in usability and interaction levels between the two scenarios was not significant and did not hinder participants from completing the tasks autonomously. The level of usability was generally good for both the LF and HF scenarios.

Diegesis

As synthesised in Figure 8-5, regarding the diegesis, participants recognized a clear difference between the LF and HF scenarios. The LF scenario was deemed suitable for the task due to the consistency of the interface graphics with the rest of the virtual environment, but it was also recognized as less authentic and less suitable for giving a real taste of a construction site. Conversely, the HF scenario received a good level of score both for being suitable for the task and for providing an effective taste of the real environment. Overall, both scenarios received a good level of scoring for diegesis, although the high fidelity scenario had a clear advantage and was recognized as more suitable for giving an idea of the work environment to young job seekers. However, it is worth noting that both scenarios were still effective in providing a sense of immersion and consistency within the virtual environment, which is an important aspect for user engagement and satisfaction. Additionally, the feedback regarding the suitability of the graphics and environment for the construction field suggests that the visual design was successful in creating a believable and engaging virtual environment for the users.

Figure 8-5: Differences in diegesis on the two scenarios.



Memory and knowledge retention

Based on the survey results sent to the participants two weeks after the experience, it can be highlighted that in the LF scenario, there was a precise recall of the actions performed but a lot of confusion regarding the tool used to complete the tasks. Most participants had difficulty remembering the tool used, which could be attributed to the use of interfaces to interact with the LF virtual scenario and the fact that many participants found the experience too simple and, therefore, not memorable. On the other hand, in the HF scenario, both the actions and tools used to complete the tasks were remembered. That could indicate that a higher level of realism can help in remembering the tools used to perform actions in an environment. However, it should be noted that the tasks were only three and were designed to be as simple and intuitive as possible for both the LF and HF scenarios. Therefore, it is essential to design user experiences that are both memorable and easy to use. By incorporating elements of realism in virtual scenarios, the user is

more likely to remember the tools used to complete the tasks. That can be particularly important in training scenarios where the goal is to provide users with a realistic experience that can prepare them for real-life situations. However, it is also essential not to sacrifice usability for realism. The user experience must balance realism and ease of use to ensure users can complete tasks efficiently and effectively.

Limitations

Both types of scenarios examined achieved a good score in all measurements without any significant differences. However, there are some differences between the scenarios. In the case of the LF scenario, a higher level of usability was perceived thanks to the constant guidance of the non-diegetic interfaces. In the case of the HF scenario, on the other hand, a greater retention of memory and knowledge was detected regarding the tools used to complete the tasks, thanks to the diegetic visual elements and the high level of fidelity of the interaction and display.

However, some limitations in terms of experiment measurement need to be presented and noted. First, two different rooms were used to test the LF and HF scenarios. The LF prototype, having no rendering problems, was tested in a room close to the participants' department of origin, as some of them were less inclined to move to another university location to reach the VR laboratory. The HF prototype, being heavier, needed to be tested inside the VR laboratory. That may have compromised the perception of immersion, as the room where the LF prototype was tested was less soundproof than the VR laboratory room where the HF prototype was tested. Secondly, although the two prototypes were tested and iterated several times in terms of usability, the lack of clarity of the instructions for the tasks may have influenced the results regarding the perception of usability of the two scenarios. Thirdly, in this experiment, only one type of diegesis was considered, i.e., a coherence of the setting and plot only visually. The limitation found at the level of visual diegetic elements was their lack of clarity when an action was completed, despite animations aiming to clarify their completion. In addition, the choice was made to apply a high level of diegesis only to the HF scenario to test the opportunities and weaknesses. This does not mean that diegetic elements cannot be applied to a scenario with low display and interaction fidelity levels. Finally, since the interaction in the LF scenario is more passive than the scene objects and more directed towards the non-diegetic interfaces, this may have influenced the retention of memory and knowledge regarding the tools to be used in the construction field context.

Limitations may include different rooms used for testing, lack of clarity in task instructions, only one type of diegesis considered that is the visual and passive interaction in the LF scenario.

09

Conclusion

This chapter presents the conclusions of the research, following the analysis and discussion of the results in the previous chapter 08 Discussion. Here, the final reflections on the experiment and research are presented, including guidelines for design choices regarding VR learning experiences.

Conclusion

Starting from the research questions and sub-questions, this paragraph will attempt to make a point of the impact of applying different visualisation techniques.

RQ: "How the level of display and interaction fidelity and diegesis of the UI and visual elements can improve the understading, the sense of presence and the flow of the young job seekers in a VR job taste experience of a vocational profession?"

Display and interaction fidelity

The research observed that the use of different levels of display and interaction fidelity did not have a significant impact on users' cognitive engagement in terms of presence, immersion, and flow. Both scenarios obtained good results, although a higher level of fidelity still obtained higher ratings. However, it is important to emphasize that measurements of memory and knowledge retention demonstrated that a higher level of interaction and visual fidelity can help to better remember actions taken and tools used. In particular, it should be noted that the level of interaction fidelity has a greater impact than display fidelity. Therefore, the use of low-resolution models such as simulations of work tools, combined with direct user interaction, could achieve the same results as using high-fidelity models with the same direct interaction methods.

Diegesis

The study found that non-diegetic visual elements like UI interfaces can improve usability, but may make tasks too easy, leading to lower user engagement. On the other hand, diegetic visual elements can increase user engagement and presence in the experience, but clear feedback is needed to avoid confusion. Using visual feedback like animations and changes in tool states can help, but adding diegetic audio feedback could make it even more effective. Animations or changes in state accompanied by sounds could help users understand feedback instantly.

Building the future guidelines

The following aims to answer the sub-research questions to create a guideline for possible strategies to follow in developing learning VR experiences.

Sub-RQ1: "Can visual elements and diegesis impact the task performance of the target user and, perhaps, the understanding of the subject matter?"

The research shows that a high level of diegesis can offer a more realistic perception and a more detailed and convincing simulation of the virtual environment. However, this requires meticulous design and continuous usability testing with appropriate feedback to help users understand the system's cause-and-effect relationship. Combining high levels of visual and audio diegesis can be useful in achieving clear feedback and a better understanding of the subject matter. Furthermore, this study suggests that a high level of diegesis does not necessarily need to be paired with high display and interaction fidelity in VR learning experiences, as diegetic elements can still work in a low-fidelity environment if designed with optimal consideration. This approach can make immersive experiences more accessible and convenient for users.

Sub-RQ2: "How visual realism and display and interaction fidelity can influence the cognitive load and level of immersion while performing a task?"

The research suggests that a higher level of detail and realism, as well as display and interaction fidelity, can increase cognitive engagement and aid in memory retention during VR learning experiences. Additionally, a higher level of diegesis can contribute to a stronger sense of immersion and presence. However, when designing high-detail experiences, it is important to consider usability and action complexity, which should be continuously tested and improved. Providing appropriate feedback and a clear understanding of the action-reaction principle is also crucial to ensure a positive user experience.

Guidelines and future work

Guidelines can be deduced from the analysis of research questions, sub-questions, and hypotheses formulated to help define design strategies for VR experiences. These guidelines are especially useful for those intended for educational purposes.

Guidelines

- A well-designed high level of display and interaction fidelity can enhance cognitive impact by stimulating a sense of presence and immersion. It can also increase user engagement and interest in completing tasks, leading to a good level of flow.

- Consistent experimentation with usability is essential to maintain a coherent and intuitive path that allows users to remain immersed in the environment without interruptions, confusion, or difficulty. Regular testing and experimentation of the usability level can help to identify areas that need improvement, ensuring that the user can remain immersed in the VR environment. This leads to smoother experiences, allowing users to concentrate more on the objectives of their interactions and improving learning mechanisms.

- A high level of diegesis combining visual elements, effects, animations, and diegetic audio can lead the user to more significant cognitive and perceptual immersion in the environment and a greater interest in the activities. However, appropriate feedback mechanisms are crucial to keep users engaged in virtual environments, especially those designed for educational purposes. Effective feedback mechanisms, such as visual cues, audio prompts, or haptic responses, inform users of their progress, guides them through the experience, and help them achieve their goals.

Future work

Finally, the study highlights the need for further exploration of the combination of VR techniques for learning purposes. The findings suggest that a low level of display fidelity, combined with good interaction and the use of diegetic visual and audio elements, could lead to similar results as those obtained with a high level of display fidelity. This could promote the use of low levels of display fidelity, which can provide benefits in terms of accessibility and inclusivity. Firstly, a low display fidelity allows for the creation of VR experiences that are less expensive to develop than those with high graphic detail. Moreover, low-fidelity VR environments can make the learning experience more inclusive for people with sensory disabilities. For example, a VR environment with low graphic complexity can facilitate access for individuals with visual impairments who may find navigating a complex and detailed virtual environment difficult. Accessibility and inclusivity are crucial aspects to consider as they opening the doors to a wider audience and improve access to VR learning for all.

References

Contributors

Ekaterina Prasolova-Førland NTNU, Leader of Innovative Immersive Technologies for Learning

Mikhail Fominykh NTNU, Researcher of Innovative Immersive Technologies for Learning

Frederik Friquin NTNU, Apprentice of Innovative Immersive Technologies for Learning

Jorge Estuardo NTNU, Researcher of Innovative Immersive Technologies for Learning

Sources

01. Nava, E., & Jalote-Parmar, A. (2022). Virtual Reality Revolution: Strategies for treating mental and emotional disorders. In 2022 IEEE International Conference on Systems, Man, and Cybernetics. Prague, Czech Republic, 3373-3378.
02. Cronin, P., Ryan, F., Coughlan, M., (2008) Undertaking a literature review: a step-by-step approach. British Journal of Nursing, 17(1), 38-43.
03. Boote, D., & Beile, P. (2005). Scholars before researchers: On the centrality of the dissertation literature review in research preparation. Educational Researcher 34(6), 3-15.
04. Design Council (2021). How do you measure design? Retrieved January 8, 2023, from https://www.designcouncil.org.uk/
05. Liu, Y., Chakrabarti, A., Bligh, T., (2003). Towards an 'ideal' approach for concept generation. Design Studies, 24(4), 341-355.
06. De Koning, J., Puerari, E., Mulder, I., Loorbach, D., (2018). Design-Enabled Participatory City Making. 1-9.
07. Interaction Design Foundation (n.d.). What is Design Thinking? Retrieved January 8, 2023, from https://www.interaction-design.org/
08. Chammas, A., Quaresma, M., & Mont'Alvão, C. (2015). A Closer Look on the User Centred Design. Procedia Manufacturing, 3, 5397-5404.
09. ISO 9241-210 (2010). ISO 9241-210. Ergonomics of Human-System Interaction – Part 210: Human-Centered Design for Interactive Systems. Geneva: International Organization for Standardization.
10. Bland, D. J., & Osterwalder, A. (2019). Testing Business Ideas: A Field Guide for Rapid Experimentation. Wiley.
11. Baskerville, R., Pries-Heje, J., Venable, J. (2011). A Risk Management Framework for Design Science Research. Scandinavian Journal of Information Systems, 26, 1-10.
12. Lau, H., Lau, K., Kan, C. (2013). The Future of Virtual Environments: The Development of Virtual Technology. Computer Science and Information Technology. 1. 41-50.
13. Cipresso, P., Giglioli, I. A., Raya, M. A., & Riva, G. (2018). The Past, Present, and Future of Virtual and Augmented Reality Research: A Network and Cluster Analysis of the Literature. Frontiers in Psychology, 9.
14. Basu, A. (2019). A brief chronology of Virtual Reality.
15. Lanier, J. (2017). Dawn of the new everything: Encounters with reality and virtual reality. Penguin.
16. Lege, R., & Bonner, E. (2020). Virtual reality in education: The promise, progress, and challenge. JALT CALL Journal, 16, 167-180.

17. Norman, D. (2013). The Design of Everyday Things. Basic Books.
18. Nielsen, J., Molich, R. (1990). Heuristic evaluation of user interfaces. Proceedings of the SIGCHI conference on Human factors in computing systems (pp. 249-256). New York: ACM Press.
19. Katona, J. (2021). A Review of Human–Computer Interaction and Virtual Reality Research Fields in Cognitive InfoCommunications. Applied Sciences, 11(6), 2646.
20. Cecil, J., Kauffman, S., Cecil-Xavier, A., Gupta, A., McKinney, V., Sweet-Darter, M. (2021). IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops, Lisbon, Portugal, 524-525.
21. Steuer, J. (2000). Defining Virtual Reality: Dimensions Determining Telepresence. Journal of Communication.
22. Bowman, D. A., McMahan, R. P. (2007). Virtual reality: how much immersion is enough? Computer, 40 (7), 36-43
23. Weidig, C., Mestre, D.R., Israel, J.H., Noël, F., Perrot, V., & Aurich, J.C. (2014). Classification of VR Interaction Techniques, Based on User Intention. EuroVR International Conference.
24. Spittle, B., Frutos-Pascual, M., Creed, C., Williams, I. (2022). A Review of Interaction Techniques for Immersive Environments. IEEE Transactions on Visualization and Computer Graphics.
25. Khan, R., Azam, F., Ahmed, S., Anwar, W., Chughtai, R., Farid, A. (2020). Comparative Analysis of Interaction Techniques in Virtual Reality. IEEE 23rd International Multitopic Conference.
26. Luciani, A. (2007). Virtual reality and virtual environment. Enaction and enactive interfaces: A handbook of terms. Enactive Systems Book, 299-300.
27. Rice, M. (2018). The role of virtual environment and virtual reality for knowledge transfer.
28. McMahan, R. P., Bowman, D. A., Zielinski, D. J., Brady, R. B. (2012). Evaluating display fidelity and interaction fidelity in a virtual reality game. IEEE Transactions on Visualization & Computer Graphics, 4(4), 626-633.
29. McMahan, R. P., Lai, C., Pal, S. K. (2016). Interaction Fidelity: The Uncanny Valley of Virtual Reality Interactions. In International Conference on Virtual, Augmented and Mixed Reality (pp. 59-70). Springer.
30. Cummings, J. J., & Bailenson, J. N. (2016). How immersive is enough? A meta-analysis of the effect of immersive technology on user presence. Media Psychology, 19(2), 272-309.
31. Nabiyouni, M., Saktheeswaran, A., Bowman, D. A., & Karanth, A. (2015, March). Comparing the performance of natural, seminatural, and non-natural locomotion techniques in virtual reality. In 3D User Interfaces (3DUI), 2015 IEEE Symposium on (pp. 3-10). IEEE.

32. Keitsch, M. M. (2014). Integrating different user involvement methods in design curriculum. Design Education & Human Technology Relations.
33. Scarr, J. (2014). Understanding and Exploiting Spatial Memory in the Design of Efficient Command Selection Interfaces.
34. Khlif, M. (2020). Virtual Reality consistency with Common Concerns of Humanity: an overview. Seventh International Conference on Information Technology Trends (ITT), Abu Dhabi, United Arab Emirates, pp. 218-223.
35. Gibson, J. J. (2014). The Theory of Affordances. The Ecological Approach to Visual Perception, 17.
36. Bhargava, A., Lucaites, K., Hartman, L., Solini, H., Bertrand, J., Robb, A., Pagano, C., & Babu, S. (2020). Revisiting affordance perception in contemporary virtual reality. Virtual Reality, 24.
37. Gibson, J. J. (2014). Events and the Information for Perceiving Events. The Ecological Approach to Visual Perception, 19.
38. Chapman, A. (2019). Haptic Feedback in Virtual Reality: An Investigation Into The Next Step of First Person Perspective Presence.
39. White, G., Fitzpatrick, G., McAllister, G. (2008). Toward accessible 3D virtual environments for the blind and visually impaired.
40. Kharoub, H., Lataifeh, M., Ahmed, N. (2019). 3D User Interface Design and Usability for Immersive VR. Applied Sciences, 9(22), 4861.
41. International Ergonomics Association. (2023). What is Human Factors and Ergonomics?. Retrieved from https://www.iea.cc/what-is-hfe/.
42. Bridger, R. S. (2018). Introduction to Human Factors and Ergonomics, 4th Edition. Boca Raton, FL, USA. CRC Press.
43. Salvendy, G., Karwowski, W. (2012). The discipline of human factors and ergonomics. Handbook of Human Factors and Ergonomics. 5th Edition. 3-4.
44. Jerald, J. (2015). The VR book: Human-centered design for virtual reality, ACM Books (Book 8), Morgan & Claypool Publishers.
45. Stephanidis, C., Kouroumalis, V., Antona, M. (2012). Interactivity: Evolution and Emerging Trends. Handbook of Human Factors and Ergonomics. 4th Edition. 1374-1378.
46. Alger, M. (2015). Visual Design Methods for Virtual reality.
47. Google Developers (2017). Designing Screen Interfaces for VR (Google I/O '17) [Video]. YouTube. https://www.youtube.com/watch?v=ES-9jArHRFHQ
48. Chen, Y., Wu, Z. (2022). A review on ergonomics evaluations of virtual reality.
49. International Organization for Standardization. (2018). Ergonomics of human-system interaction -- Part 11: Usability: Definitions and concepts (ISO 9241-11:2018).

Sources

50. Krug, S. (2006). Don't Make Me Think: A Common Sense Approach to Web Usability. New Riders Press.
51. Kamińska, D., Zwoliński, G., Laska-Leśniewicz, A. (2022). Usability Testing of Virtual Reality Applications—The Pilot Study. Sensors (Basel, Switzerland), 22(4).
52. Rhiu, I., Kim, Y., Kim, W., Yun, M. (2020). The evaluation of user experience of a human walking and a driving simulation in the virtual reality. International Journal of Industrial Ergonomics, 79, 103002.
53. Brooke J. (1996). SUS-A quick and dirty usability scale. Usability Evaluation in Industry. CRC Press, London, 4–7.
54. Schensul, S.L., Schensul, J.J., LeCompte, M.D. (1999). Essential Ethnographic Methods: Observations, Interviews, and Questionnaires.
55. Berkman, M.I., Akan, E. (2019). Presence and Immersion in Virtual Reality. In: Lee, N. (eds) Encyclopedia of Computer Graphics and Games. Springer, Cham.
56. Kim, G., Biocca, F. (2018). Immersion in virtual reality can increase exercise motivation and physical performance. In: International Conference on Virtual, Augmented and Mixed Reality, 94–102. Springer, Cham.
57. Slater M. (2018). Immersion and the illusion of presence in virtual reality. British journal of psychology, 109(3), 431–433.
58. Slater, M., & Wilbur, S. (1997). A Framework for Immersive Virtual Environments (FIVE): Speculations on the Role of Presence in Virtual Environments. Presence: Teleoperators & Virtual Environments, 6, 603-616.
59. Jerald, J. (2015). Immersion, Presence and Reality Trade-offs. The VR Book: Human-Centered Design for Virtual Reality, 2, 45.
60. Jennett, C. I., Cox, A. L., Cairns, P., Dhoparee, S., Epps, A., Tijs, T., & Walton, A. (2008). Measuring and defining the experience of immersion in games. International Journal of Human Computer Studies, 66, 641-661.
61. Slater, M. (2009). Place Illusion and Plausibility Can Lead to Realistic Behaviour in Immersive Virtual Environments. Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences, 364(1535), 3549–3557.
62. Peck, T. C., Seinfeld, S., Aglioti, S. M., and Slater, M. (2013). Putting Yourself in the Skin of a Black Avatar Reduces Implicit Racial Bias. Consciousness and Cognition, 22(3), 779–787.
63. Provancher, W. (2014). Creating Greater VR Immersion by Emulating Force Feedback with Ungrounded Tactile Feedback. IQT Quarterly, 18–21.
64. Guadagno, R. E., Blascovich, J., Bailenson, J. N., and Mccall, C. (2007). Virtual Humans and Persuasion: The Effects of Agency and Behavioral

Realism. Media Psychology, 10(1), 1–22.
65. Bye, K. (2017, February 8). An Elemental Theory of Presence + Future of AI & Interactive Storytelling. Voices of VR.
66. Csikszentmihalyi, M. (1990). Flow: The Psychology of Optimal Experience, Harper & Row, New York.
67. Nacke, L. E., Grimshaw, M., Lindley, C. A., & Lindley, S. A. (2009). Flow in games: designing for player engagement. International Journal of Human-Computer Interaction, 25(6), 531-543.
68. Pelet, J., Ettis, S., Cowart, K. (2017). Optimal experience of flow enhanced by telepresence: Evidence from social media use. Information and Management, 54(1), 115-128.
69. Witmer, B.G., Singer, M.J. (1998). Measuring Presence in Virtual Environments: A Presence Questionnaire. Presence: Teleoperators and Virtual Environments, 7 (3), 225–240.
70. Schubert T., Friedmann, F., Regenbrecht, H. (2001). The Experience of Presence: Factor Analytic Insights. Presence: Teleoperators and Virtual Environments, 10 (3), 266-281.
71. Hein, D., Mai, C., Hußmann, H. (2018). The usage of presence measurements in research: a review. International Society for Presence Research Annual Conference, Prague.
72. Schubert, T. (2003). The sense of presence in virtual environments: A three-component scale measuring spatial presence, involvement, and realness. Zeitschrift für Medienpsychologie 15, 2, 69-71.
73. Freeman, J., Avons, S., Pearson, D., Ijsselsteijn, W., (1999). Effects of Sensory Information and Prior Experience on Direct Subjective Ratings of Presence. Presence, 8(1), 1-13.
74. igroup consortium (2016). Igroup Presence Questionnaire (IPQ) overview. Igroup. Retrieved February 6, 2023, from http://www.igroup.org/
75. Jennett, C., Cox, A. L., Cairns, P., Dhoparee, S., Epps, A., Tijs, T. (2008). Measuring and defining the experience of immersion in games. International Journal of Human-Computer Studies, 66 (9), 641-661.
76. Anderson, A. P., Mayer, M. D., Fellows, A. M., Cowan, D. R., Hegel, M. T., Buckey, J. C. (2017). Relaxation with immersive natural scenes presented using virtual reality. Aerosp. Med. Hum. Perform. 88, 520–526.
77. Ijsselsteijn, W. A., de Kort, Y. A. W., & Poels, K. (2013). The Game Experience Questionnaire. Eindhoven University of Technology.
78. Lin, J., Duh, H., Parker, D., Abi-Rached, H., and Furness, T. (2002). Effects of field of view on presence, enjoyment, memory, and simulator sickness in a virtual environment. Proc. IEEE Virtual Real. 2002, 164–171.
79. Heutte, J., Fenouillet, F., Kaplan, J., Martin-Krumm, C., Bachelet, R. (2016). The EduFlow Model: A Contribution Toward the Study of Optimal Learning Environments.
80. Boletsis, C. (2020). A User Experience Questionnaire for VR Locomotion: Formulation and Preliminary Evaluation.
81. Hancock P. A., Meshkati N. (1988). Human Mental Workload. North-Holland Amsterdam.
82. Kantowitz B. H. (2000). Attention and mental workload, in Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 44, 3–456.
83. Longo, L., Wickens, C. D., Hancock, G., & Hancock, P. A. (2022). Human Mental Workload: A Survey and a Novel Inclusive Definition. Frontiers in Psychology, 13.
84. Hancock, P.A. (1987). Arousal Theory, Stress And Performance: Problems Of Incorporating Energetic Aspects Of Behavior Into Human-Machine Systems Function.
85. Suedfeld, P., Landon, P. B. (1970). Motivational arousal and task complexity: support for a model of cognitive changes in sensory deprivation. Journal of experimental psychology, 83(2), 329–330.
86. Yerkes, R. M., & Dodson, J. D. (1908). The relation of strength of stimulus to rapidity of habit-formation. Punishment: Issues and experiments, 27-41.
87. Sweller J. (2011). Cognitive load theory. Psychol. Learn. Motivat. 55, 37–76.
88. Cooper, G. (1998). Research into cognitive load theory and instructional design at UNSW.
89. Wickens C. D. (2008). Multiple resources and mental workload. Hum. Factors 50, 449–455.
90. Rubio S., Díaz E., Martín J., Puente J. M. (2004). Evaluation of subjective mental workload: a comparison of swat, nasa-tlx, and workload profile methods. Appl. Psychol. 53, 61–86.
91. Hart S. G. (2006). Nasa-task load index (nasa-tlx); 20 years later. Proc. Hum. Factors Ergon Soc. Annual Meet. 50, 904–908.
92. Longo L. (2015). A defeasible reasoning framework for human mental workload representation and assessment. Behav. Inform. Technol. 34, 758–786.
93. Tao D., Tan H., Wang H., Zhang X., Qu X., Zhang T. (2019). A systematic review of physiological measures of mental workload. Int. J. Environ. Res. Public Health 16, 2716.
94. Iwarsson S., Ståhl A. (2003). Accessibility, usability and universal design - positioning and definition of concepts describing person-environment relationships. Disability and rehabilitation, 25(2), 57-66.

95. EIDD, (2004). Design for All Europe: Stockholm declaration. Annual General Meeting of the European Institute for Design and Disability in Stockholm.
96. Mace, R. L., Hardie, G. J., Place, J. P., (1991). Accessible environments: toward universal design. Design Interventions: toward a More Human Architecture.
97. Heilemann, F., Zimmermann, G., & Münster, P. (2021). Accessibility Guidelines for VR Games - A Comparison and Synthesis of a Comprehensive Set. Frontiers in Virtual Reality, 2.
98. W3C (2021). XR Accessibility User Requirements. Available at: https://www.w3.org/TR/xaur/ (Accessed January 07, 2023).
99. Oculus (2020). Quest Virtual Reality Check (VRC) Guidelines. Available at: https://developer.oculus.com/blog/introducing-the-accessibility-vrcs/ (Accessed January 07, 2023).
100. Dajac, J., & Dela Cruz, C. (2021). Virtual Reality (VR): A Review on Its Application in Construction Safety. Turkish Journal of Computer and Mathematics Education, 12, 3379-3393.
101. Leroux, E., Caroux, L., & Sakdavong, J.-C. (2020). Diegetic display, player performance and presence in virtual reality video games.
102. P. Athen, (2020). Diegetic, Non-diegetic, and Beyond: Diegesis in Film Sound. Retrieved from https://soundfellas.com/
103. Seo, G. (2020). Implementation of Immersive Virtual Reality Through the Analysis of Diegetic User Interface. HCI International 2020. Communications in Computer and Information Science, 1225.
104. Saling, F., Bernhardt, D., Lysek, A., Smekal, M. (2021). Diegetic vs. Non-Diegetic GUIs: What do Virtual Reality Players Prefer?
105. Çamcı, A., (2019). Exploring the Effects of Diegetic and Non-diegetic Audiovisual Cues on Decision-making in Virtual Reality.
106. Marre, Q., Caroux, L., & Sakdavong, J.-C. (2021). Video game interfaces and diegesis: The impact on experts and novices' performance and experience in virtual reality. International Journal of Human-Computer Interaction, 37, 1089-1103.
107. Beck, T., Rothe, S. (2021). Applying diegetic cues to an interactive virtual reality experience. 1-8.
108. Fagerholt, E., Lorentzon, M., & Fagerholt, M. (2009). Beyond the HUD - User Interfaces for Increased Player Immersion in FPS Games.
109. Ignacio D., [GDC]. (2017). Crafting Destruction: The Evolution of the Dead Space User Interface [Video]. YouTube. https://youtu.be/pXGWJRV1Zoc
110. Shah, R. K. (2021). Conceptualizing and defining pedagogy. Journal of Research & Method in Education.

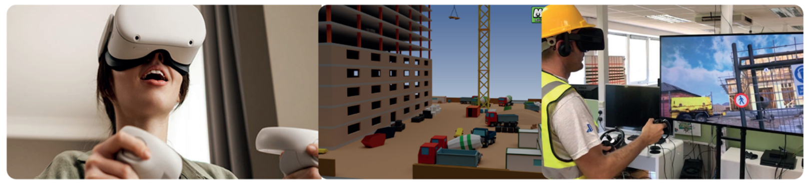
111. Kapur, R. (2020). Understanding the Meaning and Significance of Pedagogy.
112. Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. Educational Researcher, 15(2), 4-14.
113. Kolb, D. A. (1984). Experiential learning: Experience as the source of learning and development. Prentice-Hall.
114. Kolb, A.Y., Kolb, D.A. (2012). Experiential Learning Theory. In: Seel, N.M. (eds) Encyclopedia of the Sciences of Learning. Springer, Boston, MA.
115. Kolb, A.Y., Kolb, D.A. (2011). Experiential Learning Theory: A Dynamic, Holistic Approach to Management Learning, Education and Development. In Armstrong, S. J. & Fukami, C. (Eds.) Handbook of management learning, education and development.
116. Schott, C., Marshall, S. (2018). Virtual reality and situated experiential education: A conceptualization and exploratory trial. Journal of Computer Assisted Learning, 34(6), 843-852.
117. Chavez, B., Bayona, S. (2018). Virtual Reality in the Learning Process. In: Rocha, Á., Adeli, H., Reis, L., Costanzo, S. (eds) Trends and Advances in Information Systems and Technologies. WorldCIST'18 2018. Advances in Intelligent Systems and Computing, vol 746. Springer, Cham.
118. Fromm, J., Radianti, J., Wehking, C., Stieglitz, S., Majchrzak, T. A., & vom Brocke, J. (2021). More than experience? - On the unique opportunities of virtual reality to afford a holistic experiential learning cycle. The Internet and Higher Education, 50, 100804.
119. Trudeau, A. A. (2020). Virtual Reality: Opening Doorways to Experiential Learning for Students," 2020 Seventh International Conference on Information Technology Trends (ITT), Abu Dhabi, United Arab Emirates, 2020, pp. 80-82.
120. Kwon, C. (2019). Verification of the possibility and effectiveness of experiential learning using HMD-based immersive VR technologies. Virtual Reality 23, 101–118.
121. Dalgarno, B., & Lee, M. J. (2010). What are the learning affordances of 3-D virtual environments? British Journal of Educational Technology, 41(1), 10-32.
122. Petersen, G. B., Petkakis, G., Makransky, G. (2022). A study of how immersion and interactivity drive VR learning. Computers & Education, 179, 104429.
123. Radianti, J., Majchrzak, T. A., Fromm, J., and Wohlgenannt, I. (2020). A Systematic Review of Immersive Virtual Reality Applications for Higher Education: Design Elements, Lessons Learned, and Research Agenda. Comput. Educ. 147, 103778.

124. Cadet, L. B., and Chainay, H. (2020). Memory of Virtual Experiences: Role of Immersion, Emotion and Sense of Presence. Int. J. Human Comput. Stud. 144, 102506.
125. Ochs, C., & Sonderegger, A. (2022). The Interplay Between Presence and Learning. Frontiers in Virtual Reality, 3.
126. National Center for Education Statistics. (n.d.). Career and Technical Education. Retrieved from https://nces.ed.gov/programs/coe/indicator_cbb.asp.
127. U.S. Department of Labor. (n.d.). O*NET OnLine. Retrieved from https://www.onetonline.org/ U.S. Bureau of Labor Statistics. (n.d.). Occupational Outlook Handbook. Retrieved from https://www.bls.gov/ooh/.
128. Myers-Briggs Type Indicator. (n.d.). Take the MBTI Instrument. Retrieved from https://www.mbtionline.com/.
129. Swift, J., Fisher, R., (2012). Choosing vocational education: some views from young people in West Yorkshire, Research in Post-Compulsory Education, 17:2, 207-221.
130. Spilski, J., Giehl, C., Schlittmeier, S., Lachmann, T., Exner, J. P., Makhkamova, A., Werth, D., Schmidt, M., Pietschmann, M., (2019). Potential of VR in the vocational education and training of craftsmen.
131. Ofgang, E., (2022). Using Virtual Reality for Career Training. Retrieved from https://www.techlearning.com/.
132. Fominykh, M., Prasolova-Førland, E., (2019). Immersive Job Taste: a Concept of Demonstrating Workplaces with Virtual Reality.
133. Rogers, K., Funke, J., Frommel, J., Stamm, S., Weber, M. (2019). Exploring Interaction Fidelity in Virtual Reality: Object Manipulation and Whole-Body Movements. In Proceedings of CHI Conference on Human Factors in Computing Systems, 1-14.
134. Petersen, G. B., Petkakis, G., & Makransky, G. (2022). A study of how immersion and interactivity drive VR learning. Computers & Education, 179, 104429.

Appendix

A - Interviews with construction experts

I am working on a thesis that involves designing a Virtual Reality training experience for young men interested in pursuing careers in the building and construction industry. I would greatly benefit from your expertise and knowledge to create an immersive experience that prepares these individuals for what they can expect in the industry.



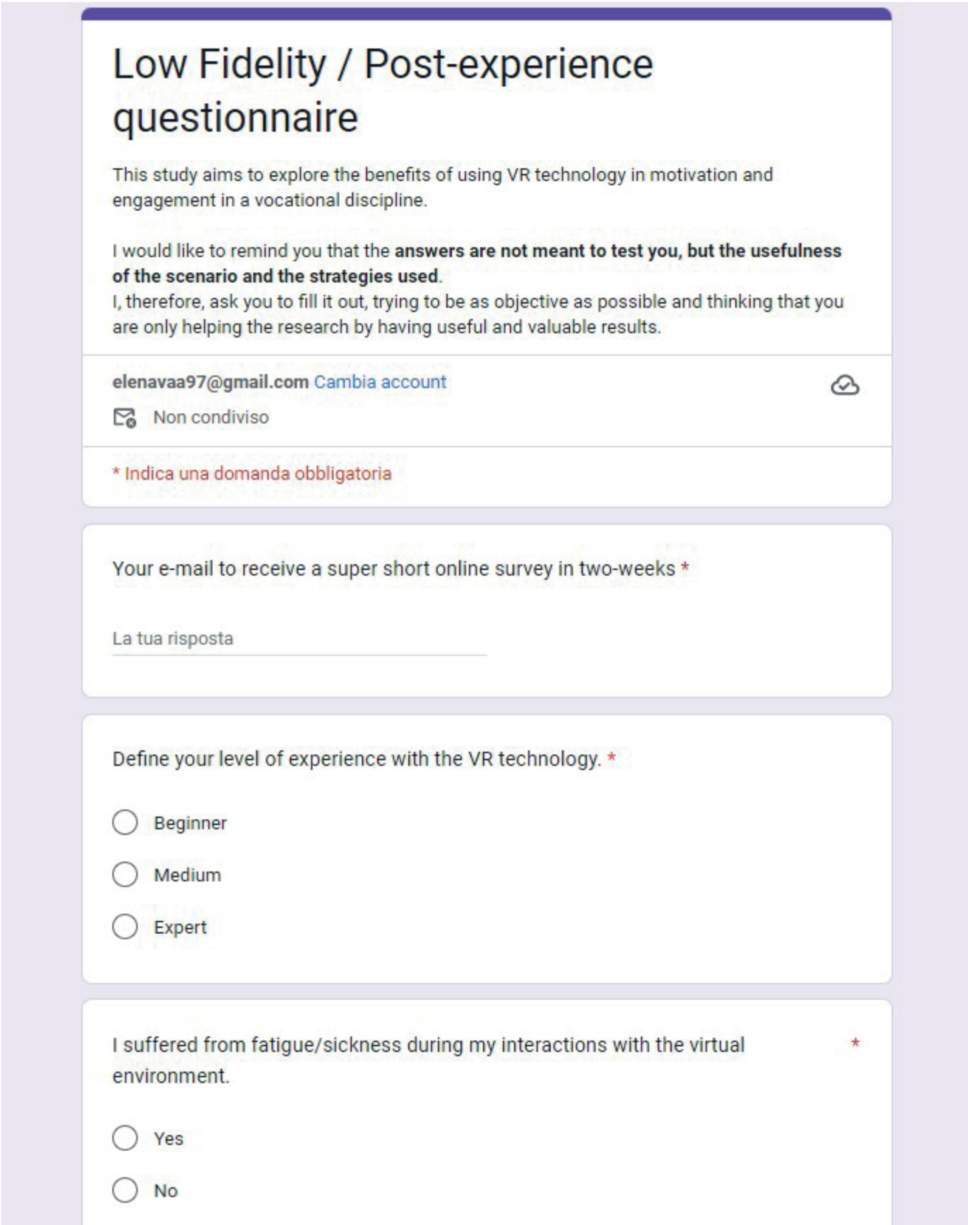
Job role: | Sector: Private / Public

Years of experience: | Country:

1. What tools do you consider essential for your work?
2. Can you briefly describe a typical working day, including how it starts, such as preparing materials and assigning tasks, and how it continues throughout the day?
3. What tasks do you typically perform most frequently during a workday?
4. Which tasks do you consider crucial and essential for the success of your work?
5. How much time do you usually allocate to each task or activity?
6. If you had to train young people, which activities or tasks would you assign to them? If you haven't trained young people before, what tasks would you recommend for them?
7. Is there anything specific that motivates you every day in your work, apart from financial incentives?
8. How long do you think it takes to gain the confidence to perform optimally in your field of work?
9. Can you recall the initial tasks that you were given when starting your first work experience?
10. What advice would you give to a young person who has recently entered the your job field?

The form was used to interview experts in the field of construction, combined with audio recordings and note-taking.

B - Post-experience questionnaire for the LF scenario



Low Fidelity / Post-experience questionnaire

This study aims to explore the benefits of using VR technology in motivation and engagement in a vocational discipline.

I would like to remind you that the **answers are not meant to test you, but the usefulness of the scenario and the strategies used**.
I, therefore, ask you to fill it out, trying to be as objective as possible and thinking that you are only helping the research by having useful and valuable results.

elenavaa97@gmail.com Cambia account

Non condiviso

* Indica una domanda obbligatoria

Your e-mail to receive a super short online survey in two-weeks *

La tua risposta

Define your level of experience with the VR technology. *

- Beginner
- Medium
- Expert

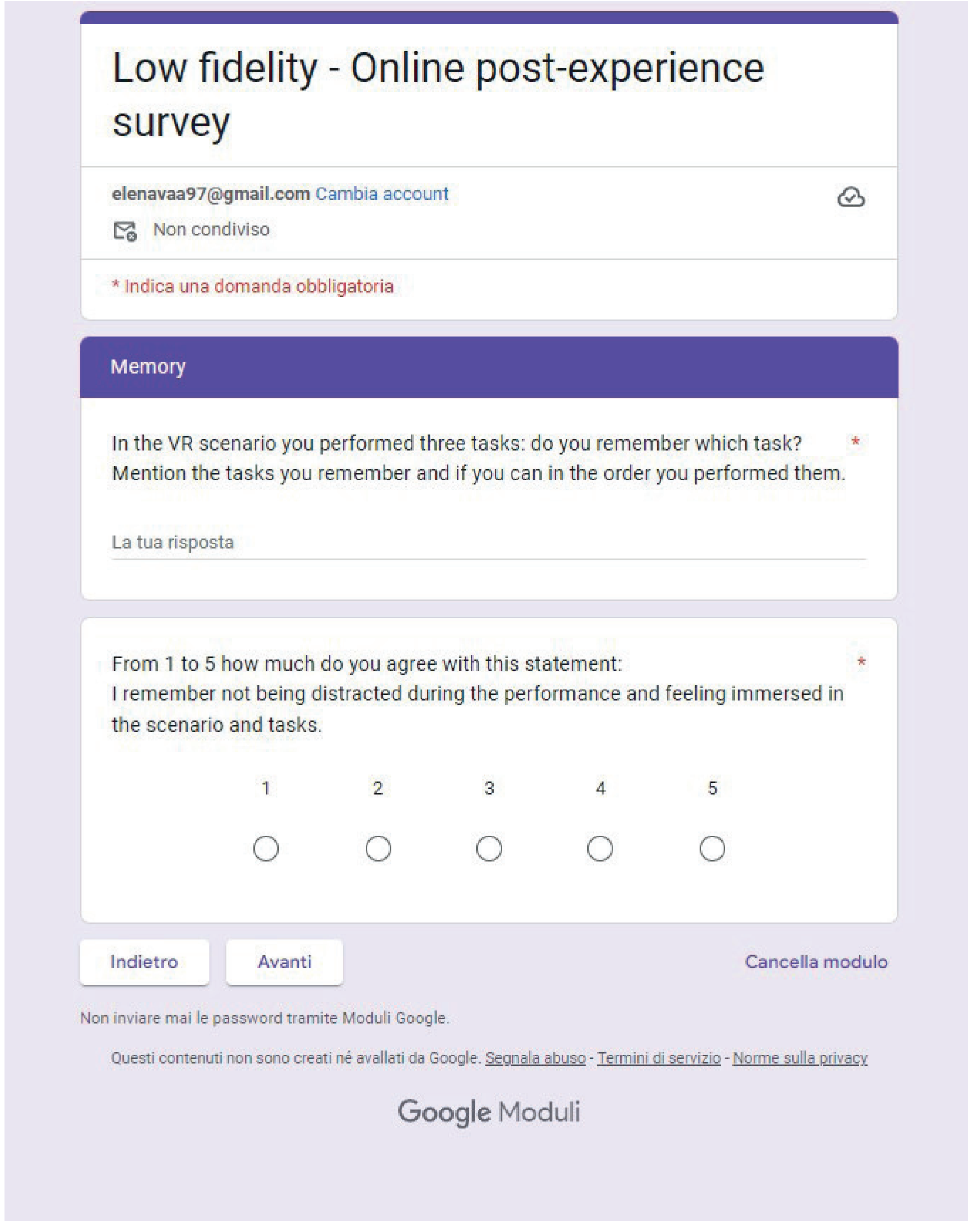
I suffered from fatigue/sickness during my interactions with the virtual environment. *

- Yes
- No

https://forms.gle/8o7zSicd5oBsh4397

The questionnaire provided to be filled to the users who tested the LF scenario. Users were asked to scan a QR code and fill in the Google Forms.

C - Survey post-two weeks on the memory of the LF scenario



Low fidelity - Online post-experience survey

elenavaa97@gmail.com Cambia account

Non condiviso

* Indica una domanda obbligatoria

Memory

In the VR scenario you performed three tasks: do you remember which task? Mention the tasks you remember and if you can in the order you performed them. *

La tua risposta

From 1 to 5 how much do you agree with this statement: *
I remember not being distracted during the performance and feeling immersed in the scenario and tasks.

1	2	3	4	5
○	○	○	○	○

Indietro | Avanti | Cancella modulo

Non inviare mai le password tramite Moduli Google.

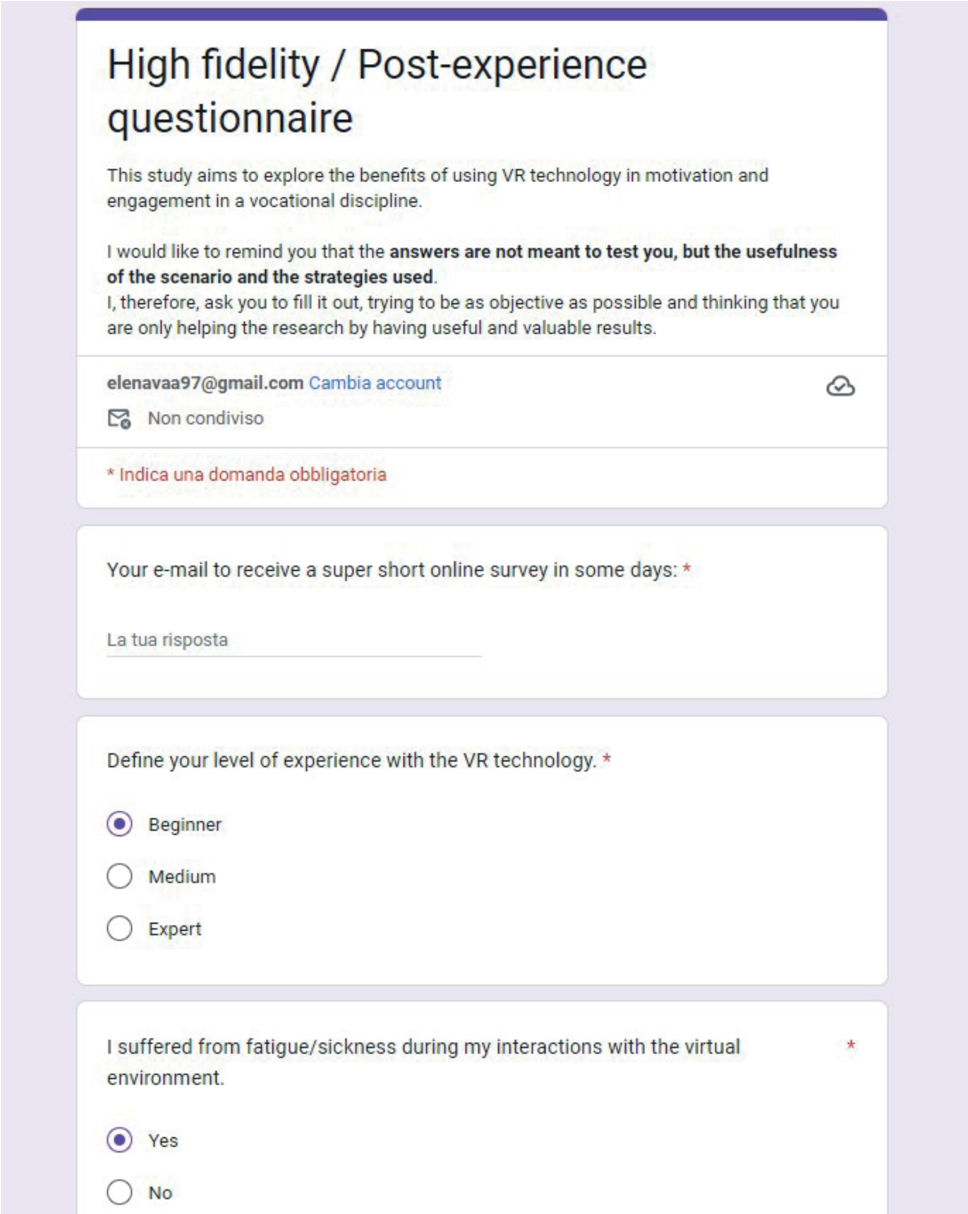
Questi contenuti non sono creati né avallati da Google. Segnala abuso - Termini di servizio - Norme sulla privacy

Google Moduli

https://forms.gle/8BRBv11bTPjSsXt98

The survey sent two weeks later to user testers who experienced the LF scenario. The link was emailed and led back to the Google Forms form.

D - Post-experience questionnaire for the HF scenario



High fidelity / Post-experience questionnaire

This study aims to explore the benefits of using VR technology in motivation and engagement in a vocational discipline.

I would like to remind you that the **answers are not meant to test you, but the usefulness of the scenario and the strategies used**.
I, therefore, ask you to fill it out, trying to be as objective as possible and thinking that you are only helping the research by having useful and valuable results.

elenavaa97@gmail.com Cambia account

Non condiviso

* Indica una domanda obbligatoria

Your e-mail to receive a super short online survey in some days: *

La tua risposta

Define your level of experience with the VR technology. *

- Beginner
- Medium
- Expert

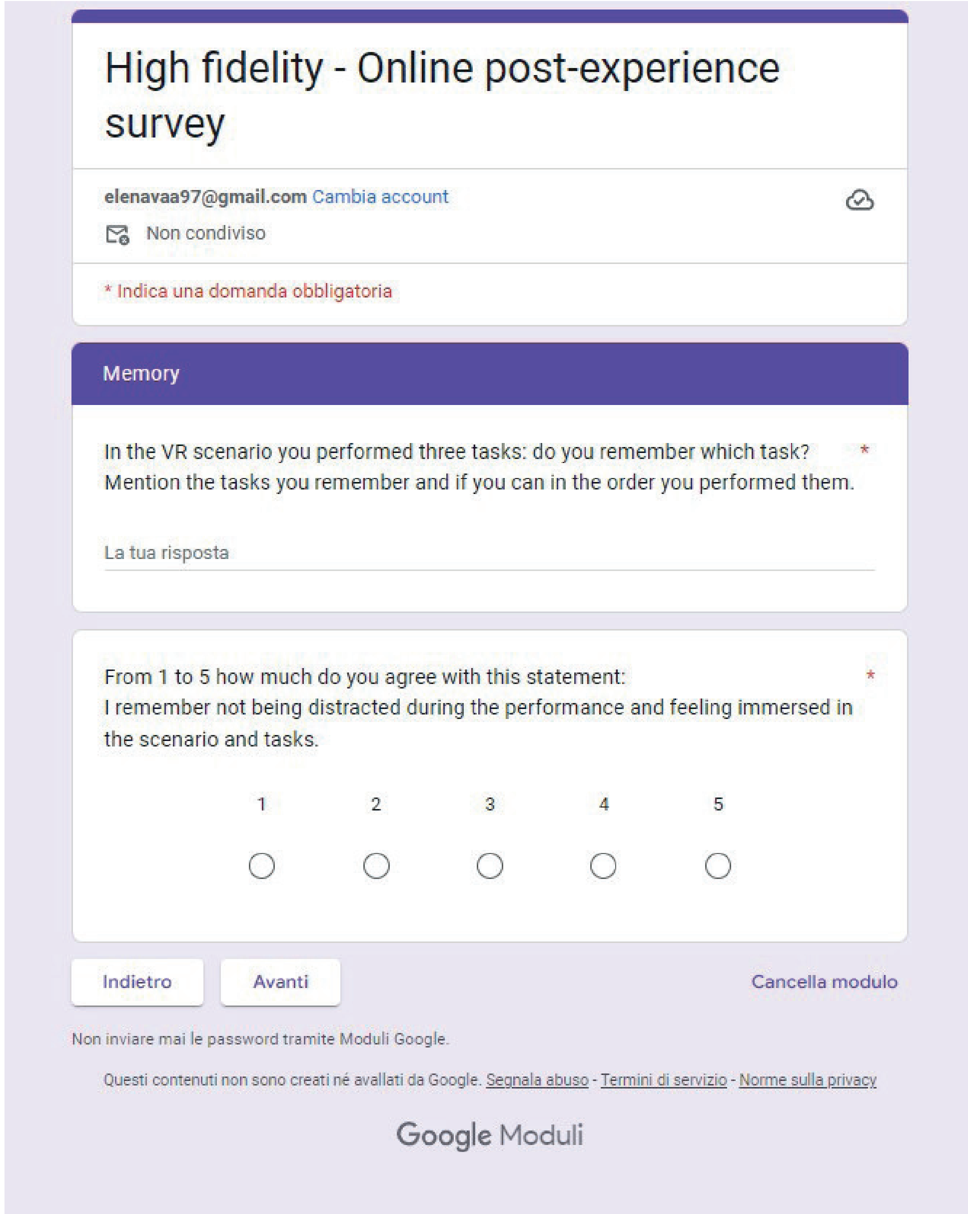
I suffered from fatigue/sickness during my interactions with the virtual environment. *

- Yes
- No

https://forms.gle/eQGEAfwRWFuRvdML8

The questionnaire provided to be filled to the users who tested the HF scenario. Users were asked to scan a QR code and fill in the Google Forms.

F - Survey post-two weeks on the memory of the HF scenario



High fidelity - Online post-experience survey

elenavaa97@gmail.com Cambia account

Non condiviso

* Indica una domanda obbligatoria

Memory

In the VR scenario you performed three tasks: do you remember which task? Mention the tasks you remember and if you can in the order you performed them. *

La tua risposta

From 1 to 5 how much do you agree with this statement: *
I remember not being distracted during the performance and feeling immersed in the scenario and tasks.

1 2 3 4 5

Indietro Avanti Cancella modulo

Non inviare mai le password tramite Moduli Google.

Questi contenuti non sono creati né avallati da Google. Segnala abuso - Termini di servizio - Norme sulla privacy

Google Moduli

https://forms.gle/FvUGZwdTnNPJM3FK6

The survey sent two weeks later to user testers who experienced the HF scenario. The link was emailed and led back to the Google Forms form.

Politecnico di Milano - School of Design
Digital and Interaction Design
Master’s degree thesis
Academic Year: 2021-2022

Eleonora Nava
Student ID: 967612