Politecnico di Torino

Politecnico di Torino

Master of Science in Computer Engineering

Graduation Session April 2024

Exploring the potential of Virtual Reality to convey information about architectural barriers and solutions: A Case Study of the KIT Campus

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Abstract

Virtual Reality (VR) is an effective tool that, thanks to its flexibility, can be used for educational purposes in a wide variety of applications. In the context of sensitisation about architectural barriers, VR is often used to simulate the feeling of being disabled which can result in the confirmation of stereotypes. An alternative approach could be to convey information about accessibility issues focusing on possible solutions to create universally accessible environments.

This study investigates the effect different ways of communicating architectural barriers in Virtual Reality (VR) have on the player's interest, comprehension, and reflective process. With the Karlsruhe Institute of Technology campus serving as a case study, a virtual replica of its cafeteria building was created. The environment can be navigated during a simulation where different architectural barriers and solutions are displayed and explained. Two representations of the accessibility issues are compared, analysing the effects of visual embellishments and sober textual explanations on the user's perception of architectural barriers.

Expert feedback on the developed prototype was collected and analysed with the Thematic Analysis (TA) method to evaluate and compare the barriers representations. The final findings highlight how the embellishments and explanations contribute to the player's curiosity, focus, comprehension, and reflection, drawing design recommendations for future applications in a similar context.

Acknowledgements

First and foremost, I would like to express my gratitude to my advisors, Prof. Fabrizio Lamberti and Prof. Kathrin Gerling for the opportunity provided by this project and for the guidance I received during the months I spent working on this thesis. I would also like to thank my co-supervisors Alberto Cannavò, Anna-Lena Meiners, and Maria Aufheimer for the efforts made in assisting and supporting me during the development of this project, that has posed many challenges and has given me a great opportunity to grow both as a professional and as an individual.

I would like to thank with all my heart all the people that were at my side before and during the development of this thesis. First, I wanna thank my family for the unconditional love and constant support that has made me feel appreciated even when at my worst, therefore I express my gratitude to Paola, Claudio, Alessia, Matteo, and Michelina. Special thanks also go to Thomas, who has been incredibly patient during the months I worked on this project and has never missed an opportunity to lift my mood and support me during every happy and difficult moment of the last year.

Finally, a deeply grateful thanks goes to all my friends and colleagues that have accompanied me for different lengths of time in life and with whom I have shared joy and tough moments during the years before and during university. Therefore, with sincere gratitude and deep affection, I thank Giulia, Andrea, Luca, and Bora for the years we shared and the moments that led to today, and Xiao, Gabriele, and Lorenzo for the experiences and adventures that we shared inside and outside of Politecnico in more recent times.

Table of Contents

List of Tables

List of Figures

Acronyms

ADA
: Americans with Disabilities Act

AEC
: Architecture, Engineering and Construction

BMUB
: Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection

CRPD
: United Nations Convention on the Rights of Persons with Disabilities

CTML
: Cognitive Theory of Multimedia Learning

DR
: Design Recommendations

HE
: Haptic Embellishments

HMD
: Head-Mounted Display

IVR
: Immersive Virtual Reality

KIT
: Karlsruher Institut für Technologie

NPC

Non-Player Character

UX

User Experience

RQ

Research Question

SDT

Self-Determination Theory

T

Theme

TA

Thematic Analysis

UI

User Interface

URP

Universal Render Pipeline

VR

Virtual Reality

VE

Visual Embellishments

XR

Extended Reality

Chapter 1

Introduction

1.1 Accessibility and Architectural Barriers

Architectural barriers within our built environment can sometimes pose challenges for individuals with disabilities. They consist of “any object in a public space that causes mobility problems or reduces access for any group of users” [1] and common examples are Steps without ramps, narrow doorways, and hallways, lack of handrails, high countertops and shelves, inadequate signage, poor lighting, and lack of accessible restrooms [2] that can limit physical access to spaces and make it more challenging for people to navigate public areas and buildings.

On the other hand, accessibility is the practice of designing buildings, products, and services to be usable by as many people as possible, regardless of age, ability, or other factors. It is a vital aspect of inclusive design, ensuring that environments are functional, safe, and welcoming for everyone. According to “Raising Awareness about Accessibility” [2], a research paper on the importance of raising awareness in design studios for better implementing accessibility for all people, accessibility is “the ability of individuals to access everywhere. Indeed, accessibility is a technical item which expresses “an umbrella term for all parameters that influence human functioning in the environment”. It is believed that a well-designed urban environment is livable and readily accessible for everybody. [. . .] Social theorists consider accessibility as the right of being a member of the society. Accessibility is also a guiding principle of urban design in the United Nations Conventions where equal opportunities for everybody are encouraged in each physical arrangement for public use. As a result of the aforementioned explanation, accessibility must be provided for all people living in the society regardless their age, ability or status in life in order to benefit from the built environments.” [2]. Therefore, accessible design features, such as ramps and elevators, wider doorways and pathways, adjustable lighting, and accessible restrooms play a crucial role in enhancing the accessibility of buildings and public spaces. These features enable individuals with disabilities to navigate and interact with their surroundings independently and comfortably.

In many countries, laws and regulations have been established to promote accessibility and ensure that public and private spaces are accessible to everyone. For example, the Americans with Disabilities Act (ADA) [3] in the United States prohibits discrimination based on disability and mandates accessibility standards for buildings and infrastructure. Similarly, the United Nations Convention on the Rights of Persons with Disabilities (CRPD) [4] emphasizes the right of persons with disabilities to access the physical environment, transportation, information, and communication on an equal basis with others. These legal frameworks provide guidelines and requirements for eliminating architectural barriers and accommodating individuals with disabilities in various aspects of daily life. Under German law, "people with disabilities are entitled to help and assistance in order to avert, eliminate or improve their disability. The general goal is to overcome, as much as possible, the disability's effects and to enable the disabled to participate in all areas of society, especially in the labor market and in community life. The Federal Government is obliged to a barrier-free design and construction of public buildings, streets, etc." [5]. In the context of accessibility and German law, the following definitions from "Disability Law in Germany: An Overview of Employment, Education and Access Rights" [5] are reported here to better understand the foundations of this study.

Discrimination of disabled people refers to the situation where "disabled and non-disabled people are treated differently without a just cause and as an effect of the treatment the disabled person's equal participation in social life is directly or indirectly impaired." [5].

For education, "Universities are required, in the most feasible way, to take the special needs of disabled students into consideration to avoid discrimination against disabled students and to enable them to participate in university activities without outside help." [5].

In public buildings access the aim is "at equal participation in community life for disabled people by eliminating obstacles to mobility in the areas of construction and transport as well as in the area of communication. It is intended to create an obstacle-free, safe environment for the disabled to enable them to live without outside help as much as possible." [5].

Therefore, to favor accessibility of public buildings, environments must be barrier-free, so that "disabled people are able to access and use them in the general and usual way without specific difficulties and generally without outside help." [5]. Accessible design in buildings focuses on creating environments that are simple and intuitive, flexible and error-tolerant so that they can be equitable in use while requiring low physical effort [6]. These design features aim to enhance and improve the overall usability of buildings and public spaces for everyone.

An emerging theme is that of universal design. The concept expands on the principles of accessible design by aiming to create products, environments, and systems that are usable by all people, to the greatest extent possible, without the need for adaptation or specialized design. In fact, “There is a recognition that design which is functional for persons with handicaps is also utilitarian for the elderly, the very young, and the temporarily disabled.” [7]. By integrating principles of flexibility, simplicity, and inclusivity, universal design enhances accessibility and improves usability for a broader range of individuals since, according to The Handicapped Affairs Office of San Antonio, fifty-six percent of the community benefits from barrier-free design [7]. Architects, designers, and planners are encouraged to consider the diverse needs and abilities of all users when designing buildings and public spaces, promoting innovation and inclusivity in the built environment.

This thesis places itself in the context of raising awareness about accessibility and inclusive building design by means of a prototype Virtual Reality (VR) simulation that sensitizes about architectural barriers. The belief is that, as stated in “Raising awareness about accessibility”, “the more designers know about the different user needs the better they will apply into real world” [2], and that education and student’s awareness on accessibility are the means to reach that goal [2].

1.2 Improving Accessibility Awareness with VR

VR technology enables users, by means of a mounted headset and two controllers, to experience virtual replicas of real or fictional environments in a safe and reproducible setting. Recognized for its immersive capabilities, VR offers engaging interactive experiences with a high degree of flexibility. According to the paper "Current and Potential Uses of AR/VR for Equity and Inclusion" [8], immersive experiences in VR surpass two-dimensional counterparts in providing realistic interpersonal and sensory experiences, thereby creating new opportunities for digital communication, and mirroring the physical world.

VR is believed to have the potential to be a powerful tool for nurturing empathy and raising awareness toward inclusion. The paper [9] shows how simulations within VR have demonstrated high potential to prompt reflection, spark social change, and mitigate the harmful impact of biases toward individuals with impairments such as mobility difficulties, vision deficits, autism, and limitations due to pregnancy.

VR has been widely used in the past to create immersive, first-person experiences with the goal of creating a tool to raise awareness and build empathy and understanding of the challenges faced by people with different impairments in their everyday lives to foster inclusion.

A prevalent method used to raise awareness and foster empathy toward disabled people is the prospective-taking approach that simulates the experience of being disabled when completing tasks [10] or experiencing virtual environments [8] [9]. Within a VR simulation, individuals feel a sense of embodiment with their virtual avatar even in the case where their physical appearance is not reflected. This connection between the user and their virtual representation allows altering the capabilities or the way in which users experience their virtual surroundings, "demonstrating what it is like to have a disability" [8]. This simulation approach brings participants to experience at a visceral level the struggles and difficulties faced by disabled individuals [11].

While the usage of impairment simulations is often encouraged in education, rehabilitation, and counseling to reduce prejudice towards people with disabilities, challenges and ethical issues of this approach have been highlighted [12]. Numerous studies report that poorly designed simulations can lead to unintentional attitudinal shifts, increased anxiety about working with individuals with disabilities, and misunderstandings about disability experience [13]. Simulating disabilities may subvert the intended educational value of the experience, emphasizing early-onset limitations rather than exposing the responsibilities of structural barriers [11]. The potential implications of showing participants how their own capabilities would be severely limited if they suddenly became disabled include increased stigmatization and discrimination against disabled people, that are perceived as less capable of work and independent living [14].

A different perspective is suggested by the qualitative study [15], which reports how people with physical and sensory impairments involved in the inquiry see VR as a promising advocacy tool when the simulations focus on how environmental barriers and social attitudes around people with disabilities disable them, rather than focusing on impairment exercises.

This study takes advantage of the agreement on the potential of VR simulations to foster empathy, raise awareness, and teach about disabilities as ground to build this prototype. But, as opposed to disability simulations in a virtual environment, this project aims at building a simulation to highlight architectural barriers and poor design choices that have an impact on buildings' accessibility and disabled people's inclusion.

1.3 Goal of the Study

In an evolving world that increasingly recognizes the importance of inclusivity and accessibility, addressing architectural barriers has become a vital consideration for public institutions [16]. Architectural design choices on university campuses can, at times, pose challenges for students with disabilities (see Section 1.1).

VR has been explored as a valuable tool for educating and raising awareness about the challenges faced by people with disabilities (see Section 1.1). However, some previous approaches have unintentionally led to misconceptions (see Section 1.1). A common approach is to simulate the experience of having a disability, which could reinforce stereotypes of helplessness and vulnerability. An alternative possibility is presented in this study (see Section 1.1), which aims to convey information about architectural barriers without simulating disabilities. The goal is to shift the focus from the difficulties induced by having disabilities when circulating public spaces to the responsibilities of the architectural design choices that are sources of discrimination.

The primary objective of this study is to investigate the impact of visually engaging design elements on the user's understanding and reflection on architectural barriers (see Section 2.4) when the considered disabilities are not simulated. The two following research questions are addressed:

RQ1: How can juicy design elements and embellishments be used to appropriately simulate the experience of moving in the reproduced space and to communicate barriers?

RQ2: How do the used design elements affect player experience and how do they contribute to the user's reflection on the barriers in the space?

To answer the research questions, a VR simulation composed of two parts was designed (see Chapter 3), built (see Chapter 4) and assessed with expert interviews (see Chapter 5). The KIT campus cafeteria was chosen to be reproduced as a virtual environment (see Section 3.3) where architectural barriers and solutions would be displayed. The chosen building served as a case study, allowing the exploration of how VR technology can enhance awareness and critical thinking regarding architectural barriers. Within the created VR simulation, users were given the opportunity to navigate the environment while being informed, through examples and explanations, about inaccessible design choices and solution suggestions.

A group of five experts (see Section 5.1.3) specialised in the fields of architecture design, buildings' accessibility, and barriers for disabilities was involved to assess the effectiveness of the built simulation. The collected feedback was analysed (see Section 5.2) to create a guideline of findings (see Section 6.2) and define a set of design recommendations (see Section 6.3).

The experts evaluating the simulation were exposed to two versions of the barriers that differed in terms of compelling design elements and explanation delivery means (see Section 3.1). The first representation (see Section 4.7) used embellishments, effects, and animations to highlight inaccessible elements in the environment, concurrently providing information on the modifications needed to create an inclusive version of the space. In contrast, the second representation presented to the users in a later segment of the simulation (see Section 4.8) relied on straightforward and sober textual descriptions to affirm or enhance the user's comprehension of each barrier's characteristics. The goal was to evaluate the appropriateness, informativeness, and completeness of both sets of barrier representation techniques, additionally focusing on the user experience and the prompted reflection.

The subsequent chapters will cover the theoretical foundations of VR simulations for accessibility and features relevant to the design and implementation (see Chapter 2). The discussion addresses then the design (see Chapter 3) and implementation (see Chapter 4) phases of the simulation development. The evaluation methodology of the prototype is explained in Section 5 and the findings follow in Section 6. To conclude, a discussion section will contextualize the results obtained from the experts' feedback (see Chapter 7) and final considerations can be found in Chapter 8.

Chapter 2

Background

This chapter aims to provide a comprehensive overview of the background information and literature interventions essential to understand the perspective adopted by this project (see Section 1.3). The goal of this study is to evaluate the effectiveness of juicy design elements and embellishments (see Section 2.4) in communicating architectural barriers, positively affecting User Experience (UX), and fostering reflection about accessibility. VR simulations have been adopted in the past to foster empathy about inclusion by simulating disabilities and impairments in the virtual environment (see Section 2.1). The method has demonstrated to have limitations and this thesis investigates a possible alternative approach. Leveraging the existing idea of using VR simulations to support architectural design (see Section 2.2), a virtual experience was designed (see Chapter 3) and created (see Chapter 4) to present and explain architectural barriers and solutions to participants. To raise awareness about inclusion without simulating disabilities, an existing framework for educational simulations (see Section 2.3) was utilized as guidelines to define the structure of the experience and its features.

2.1 Virtual Reality Simulations to Foster Empathy

Augmented Reality (AR) and VR are two distinct but related technologies that are increasingly used in a wide variety of contexts for their immersive and engaging ways of enabling users to interact with digital content along with physical surroundings.

AR is a technology that overlays digital information onto the real-world environment. AR enhances the user's perception of reality by integrating virtual elements, such as images, text, or animations, into the physical world. This technology is commonly experienced through mobile devices, smart glasses, or specialized

AR headsets. On the other hand, VR immerses users in a simulated, computer-generated environment. VR technology typically involves wearing a headset that covers the user's eyes, blocking out the physical world and replacing it with a virtual one. This immersive experience allows users to interact with and navigate through virtual environments as if they were real.

While AR enhances the real-world environment by adding virtual elements and users to remain aware of and interact with their physical surroundings, VR creates a completely artificial environment that replaces the real world, providing a more immersive and isolated experience.

2.1.1 Potential of AR and VR for Equity and Inclusion

AR and VR technologies offer significant potential in enhancing awareness and understanding of accessibility issues, thereby contributing to equity and inclusion efforts. These technologies and applications have potential in being inclusive of all users thanks to their flexibility and high adaptability that allows customising experiences depending on the participants specific needs and preferences. Additionally, immersive technologies offer possibilities to design and create engaging and realistic experiences that can be adapted to a wide variety of scenarios and provide improved opportunities with respect to their two-dimensional counterparts in terms of immersion and generated interest.

AR and VR can play a crucial role in increasing public awareness and prompting social change to mitigate the harmful impacts of ableism, racism, sexism, and other forms of bias. For instance, immersive empathy interventions can be designed to simulate the experience of navigating life with a disability or assuming the identity of a person of a different race, gender, or other characteristic. While purely empathy-oriented embodiment exercises are somewhat controversial, there is recognition that these technologies could be valuable in informing inclusive design of both virtual and physical spaces [8].

VR and similar technologies have shown to be valuable tools to foster empathy on accessibility and inclusion. A possibility to foster empathy is to simulate impairments like mobility difficulties, vision deficits or autism by immersing users in simulated environments that replicate the experiences of those with different abilities. The recent study “Inclusion and adaptation beyond disability: Using virtual reality to foster empathy” [9] suggests that extended reality (XR) technologies like AR “have interesting potential as a means of simulating the functional effects of vision impairment in normally sighted individuals” [9]. On the other hand, “VR simulations can replicate the sensory sensitivities and social challenges associated with autism, fostering empathy, and promoting acceptance of individuals on the spectrum.” [9].

The study highlights that immersive experiences enabled by VR or AR have significant potential to cultivate empathy towards disability by authentically replicating the everyday challenges faced by individuals with disabilities. In fact, “VR can provide immersive experiences that allow individuals to step into the shoes of others, sharing their joys and tribulations on a deeply visceral level. By nurturing empathy, VR has the potential to spark profound social change, foster genuine inclusivity, and shape a world where empathy triumphs, and the power of understanding paves the way to a more compassionate and inclusive society” [9]. These technologies offer a genuine sense of presence and embodiment, allowing users to actively participate in simulated environments that mirror the physical and sensory realities of living with a disability. This hands-on engagement fosters profound empathy as users confront the physical, emotional, and social barriers encountered by people with disabilities, leading to a greater understanding of their perspectives and struggles. Additionally, the controlled learning environment provided by immersive experiences allows users to explore diverse scenarios and situations without real-world consequences, facilitating experiential learning and deepening empathy beyond the limitations of traditional education or awareness campaigns.

2.1.2 Perspective-Taking Approach in Simulations

VR has been extensively utilized to develop immersive, first-person experiences aimed at raising awareness and cultivating empathy and understanding for the challenges encountered by individuals with various impairments in their daily lives, with the ultimate objective of promoting inclusion and sensitising about accessibility. Multiple example of perspective-taking experiences to foster empathy toward disabled people and improving attitude towards disabled peers exist among development of VR simulations.

An example of software developed to sensitise about architectural barriers in schools with the perspective-taking approach is presented in the paper “Using Virtual Reality to Teach Disability Awareness” [10]. In this experiment a desktop VR program was designed and evaluated to teach children about the accessibility and attitudinal barriers encountered by their peers with mobility impairments in an educational environment. The simulation takes place in the exterior and interior area of a school and, within the experience, children sitting in a virtual wheelchair experience obstacles such as stairs, narrow doors, objects too high to reach, and attitudinal barriers such as inappropriate comments. In this case, the mobility aid is not physically replicated, but participants experience the disability by being represented as sitting in a wheelchair during the experience. Figure 2.1 shows an example of an attitudinal barrier presented to a participant during the desktop VR program. Particular focus during the development of the experience was given to accurately design and program the wheelchair mobility and manoeuvrability in the virtual environment. The paper refers that “although this provided a sense of frustration for the children tested on the program, it served to provide a sense of environmental constraints as well as to highlight the capabilities of their peers who use a wheelchair” [10]. Therefore, this program belongs to the category of perspective-taking simulations, where disabilities are simulated to stress the fact that having impairments negatively affects individual’s life and causes frustration.

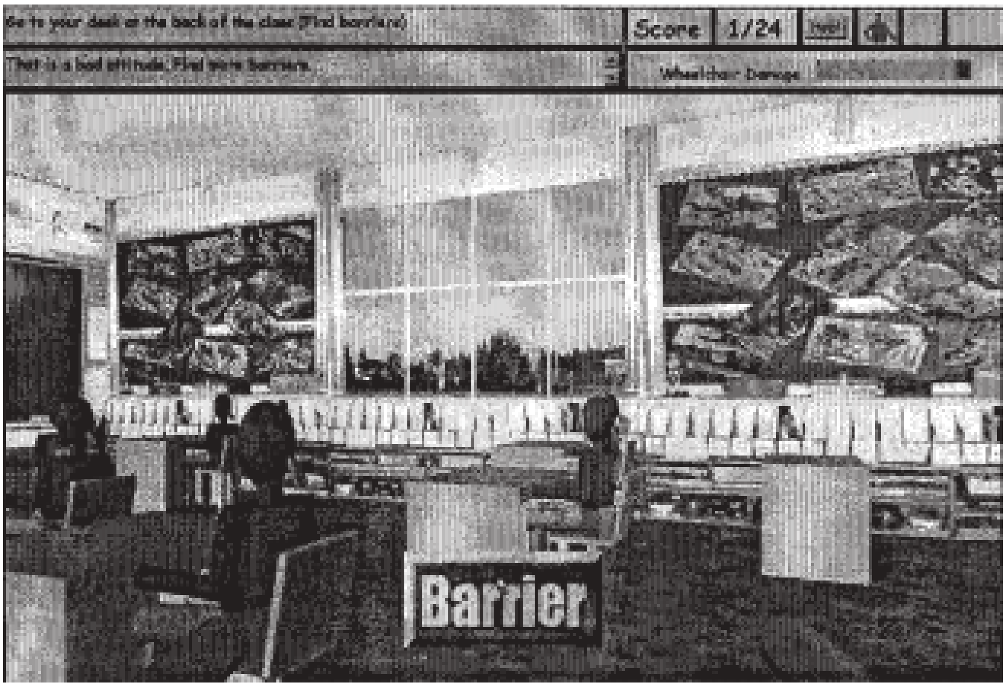

Figure 2.1: Scene from "The Barriers" software developed to sensitize about architectural and attitudinal barriers with children in school. The image is from the paper “Using Virtual Reality to Teach Disability Awareness” [10] that discusses the experiment.

2.2 Virtual Reality Simulations for Architectural Design

This section investigates the potential of VR simulations as educational tools to inform about the impact of architectural barriers and design choices on buildings’ accessibility.

Several tools exist to build 3D representations of urban spaces and architectural designs from early-stage plans. As shown by "Virtual Reality Simulators for Inclusion and Participation: Broadening Perspectives on Accessible Cities and

Public Space" [17], "Dynamic Simulation in Virtual Environments as an Evaluation Tool for Architectural Design" [18], and "Visualisation in Architecture, Engineering and Construction (AEC)" [19], VR simulations can be used to improve decision-making and product quality when designing buildings or urban spaces. Designers are allowed to experience the built environments already in the early stages of a project solving conflicting situations among users sooner than without the aid of a virtual replica. The applications are also built with the intent of addressing the specific needs of often neglected groups in public spaces, accounting for accessibility and inclusion issues. Figure 2.2 shows a VR model assembled in a generic VR Tool using CAD house type data, and site layout data from "Visualisation in Architecture, Engineering and Construction (AEC)" [19]. The paper "Towards the inclusion of wheelchair users in smart city planning through virtual reality simulation" [20] additionally suggests that the introduction of VR simulations during the planning phase of smart cities can allow wheelchair users to directly explore the planned buildings and urban environments, providing valuable feedback about accessibility. The study created a tool that allows wheelchair users to experience VR simulations while manoeuvering their wheelchair on a set of rollers. Figure 2.3 shows how users can explore and examine planned digital building models with their own wheelchair, to experience the environment and provide feedback on accessibility.

Figure 2.2: VR model assembled in a generic VR Tool using CAD house type data, and site layout data from "Visualisation in Architecture, Engineering and Construction (AEC)" [19].

In the context of teaching architectural design, study [21] suggests that the idea of introducing VR tools in architecture design education is found “attractive, stimulating, and original”, and has the potential to enhance students learning outcomes by providing a more immersive and interactive learning experience. It was shown by [10] that VR can be used as an efficient tool to enhance the quality of students’ design. By providing a 3D virtual replica of the planned ideas where students are allowed to experience the environment and investigate design choices with their tutors. The issue reported by [21] suggests that the integration of VR software in architecture education curriculum is at risk of being confusing and inefficient because of the complexity of the software available.

An educational tool to instruct students about common architectural barriers in an inviting, intuitive, and interactive way is according to us missing. Existing software is unnecessarily complex because adaptable to all kinds of designed architectural plans, while this research group believes that a simpler tool to highlight common barriers by using a single virtual environment where common bad practice examples can be highlighted would be instructive and useful to gain basic knowledge on the topic in a short amount of time.

Figure 2.3: Example of indoor application of 3D Model City Planning Software where users can explore and examine planned digital building models with their own wheelchair (photomontage of actual rendering) from paper "Towards the inclusion of wheelchair users in smart city planning through virtual reality simulation" [20].

This study aims to create a virtual replica of an existing environment and to prototype mechanisms to interact with architectural barriers while being informed about poor design choices and possible alternatives. By displaying accessibility issues and possible solutions to three architectural barriers in the reproduced environment, this project's goal is to create the prototype of an educational tool to sensitize about the impact of architectural barriers without participants undergoing the unnecessary struggle and frustration of being suddenly disabled.

2.3 Educational Simulations Construction

To build a VR educational tool, guidance on the construction of the simulation was sought in the literature. The study "A Framework for the Use of Immersive Virtual Reality in Learning Environments" [22] provides a comprehensive guide for designing effective Immersive Virtual Reality (IVR) learning experiences based on the Cognitive Theory of Multimedia Learning (CTML) [22]. Suggestions from the guide were used when building the prototype simulation of this study, designed to educate about architectural barriers and building accessibility. IVR differs from VR in the achieved immersion and interactivity by using more advanced techniques to completely cover the player's visual field. The guidelines suggested by this study were deemed suitable to be applied to the VR educational simulation built for this project because of the similarities of the two tools as discussed in Table 2.1.

CTML [22] is a framework for designing effective multimedia learning environments and is based on three principles of learning: dual coding theory, limited capacity theory, and active processing theory.

According to the dual coding theory, people process information in two different channels, visual and auditory. The Limited Capacity theory suggests that people have a limited capacity for information processing, so instructional material should be designed to avoid overloading learners' cognitive resources [22]. The Active Processing theory suggests that learning is an active process that involves constructing mental models, so instructional materials should be designed to encourage learners to engage with the material and make connections between new and existing knowledge [22].

Additionally, the study on IVR in learning environments identifies three key features of simulation technology: interaction, immersion, and imagination. Interaction refers to the ability of learners to actively engage with the virtual environment, immersion refers to the sense of presence and realism that the virtual environment creates, and imagination refers to the human mind's capacity to perceive non-existent things [22].

The recommendations in the framework were adapted to the scope and needs of this project as shown in Table 2.1 and the indications are followed during the design (see Chapter 3) and development (see Chapter 4) of the prototype of this study as described in Table 3.1. The suggestions gathered from the literature are compared with the results of this experiment in Table 7.1.

Suggestion [22]	**Description [22]**
"Learning first, immersion second"	On behalf of the instructional goal, it is recommended to "reduce extraneous processing" and to carefully think about the grade of immersion necessary. If a higher degree of immersion is not relevant to achieving the learning objective, here, less is more"
"Provide learning relevant interactions"	Two recommendations are proposed to optimize learning in terms of interactions: - Avoid unneeded and learn-irrelevant interactions. - Enable the learners' pre-training, not only in terms of basic concepts but also on how to use the interaction tools.
"Segment complex tasks in smaller units"	Content in IVR learning environments has a high risk of overwhelming learners. Therefore, it is concluded that breaking down complex tasks into small segments is effective for managing essential processing in IVR.
"Guide immersive learning"	The role of guidance is still debated. Even if there seems to be at least some agreement that completely unguided discovery learning is not useful due cognitive overload issues. The debate is about timing and form of guidance for effective learning.
"Build on existing knowledge"	To foster learning activities, new information should be balanced with prior knowledge to avoid under- or overstimulation. Worked examples and tutorials may help learners with a low level of prior knowledge, but hinder learners with a high level of prior knowledge. We recommend determining learners' current level of knowledge and adjusting the severity as well as the amount of support provided.

“Provide constructive learning activities”	The learner’s enjoyment during the IVR lesson was not diminished by adding generative learning strategies. This means that IVR has the potential to be effective for learning and at the same time makes learning more enjoyable than traditional media. We recommend providing additional constructive learning activities that enable learner’s knowledge construction.

Table 2.1: Recommendations to build educational simulations [22]

2.4 Juiciness, Embellishments and Player Experience in VR

The goal of this project is to assess the effects of visually engaging design elements on UX, understanding, and reflection on architectural barriers and accessibility issues (see Chapter 1).

To answer the research questions of this study (see Chapter 1), the definition of four fundamental concepts, as interpreted by "Juicy Game Design: Understanding the Impact of Visual Embellishments on Player Experience" [23] and "Playful Reflection: Impact of Gamification on a VR Simulation of Breastfeeding" [24], is necessary:

- Visual Embellishments (VE) are defined as design elements that have no effect on system functionality but are thought to contribute to the overall user experience. They are decorative or ornamental elements that enhance the visual appeal of a game without directly impacting its core mechanics; examples can be graphical detail and audiovisual effects.

- Juicy design elements are components designed to provide redundant feedback in situations where a single user’s action triggers multiple non-functional reactions. Juiciness is a design term used in the games industry to describe a particular type of game feel, achieved by abundant audiovisual effects. It is defined as a phenomenon that emerges from the coherent design of game mechanics and visuals while providing confirmatory, explicit, and ambient feedback.

- UX is a broad term that refers to a user’s emotions and opinions that they form when playing a game. UX research has linked engaging experiences with the fulfillment of users’ psychological needs defined according to the Self-Determination Theory (SDT) which has been used as a measure of intrinsic motivation, which is fostered through satisfying human needs for competence, relatedness, and autonomy.

- Refection is a process that involves revisiting thoughts that challenge the current individual's understanding of a subject, offering an incentive to view the subject from different perspectives and thereby, potentially leading to transformative thoughts or behaviors.

The introduction of juicy design elements and VE in the architectural barriers' highlighting and solutions' demonstration is the key aspect of this project. The aim is to investigate the effects of these constructs, evaluated by the literature in multiple gaming and VR contexts, on UX and prompted reflection on accessibility issues in the built virtual environment.

Juiciness is shown in "Understanding the Effects of Gamification and Juiciness on Players" [25] to improve user experience in non-gaming settings by satisfying all the user's basic psychological needs as defined in the SDT. Because of the fulfillment of perceived competence, autonomy, and relatedness, users are intrinsically motivated to complete tasks and engage more with the proposed activities. Figure 2.4 shows an example of a visual break down of the juicy VE that are displayed when the user establishes gaze over the prey in sequential order from the paper "Understanding the Effects of Gamification and Juiciness on Players" [25].

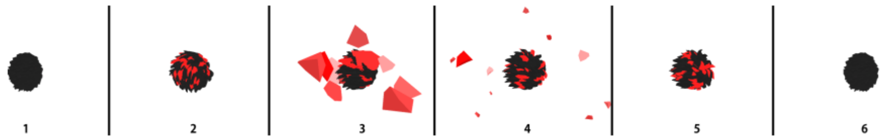

Figure 2.4: Visual break down of the juicy VE that are displayed when the user establishes gaze over the prey in sequential order from "Understanding the Effects of Gamification and Juiciness on Players" [25]

Juiciness and VEs, as shown by "Juicy Game Design: Understanding the Impact of Visual Embellishments on Player Experience" [23], improve UX in terms of visual appeal and related constructs such as curiosity, immersion, and meaning. On the other end, though, VE should be balanced by other design elements to avoid overwhelming users and distracting them from the overall experience. Figure 2.5 shows an example of embellishments applied to the game Cuber, developed to study the effects of juiciness on UX for the paper "Juicy Game Design: Understanding the Impact of Visual Embellishments on Player Experience" [23]. Figure 2.6 shows a second example of embellishments introduced to study juicy design applied to the game Dungeon Descent [23].

Findings on the effects of visually engaging design elements on performance and engagement in educational games are studied by "Toward Understanding the

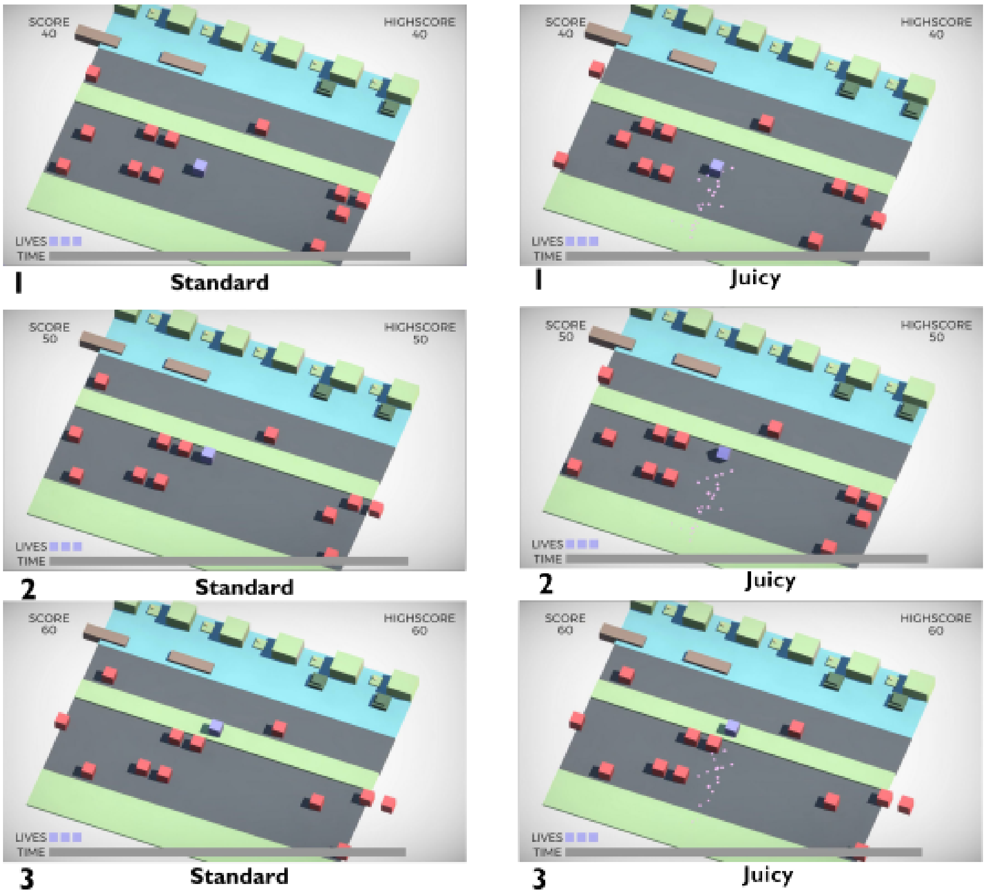

Figure 2.5: Presentation of gameplay in Cuber as the player progresses through the game (left column: standard version, right column: juicy version) developed to study the effect of Juiciness on UX by "Juicy Game Design: Understanding the Impact of Visual Embellishments on Player Experience" [23]

Impact of Visual Themes and Embellishment on Performance, Engagement, and Self-Efficacy in Educational Games" [26]. It is suggested that VEs in the form of game skins, (coherent, interchangeable sets of graphical assets) have opposite and complementary effects on engagement and performance.

Additional constructs that can be included within the concept of redundant feedback are the so-called Haptic Embellishments (HEs) and juicy haptics. These constructs are respectively defined by [27] as haptic feedback used to reinforce information already provided through other means (e.g., via visual feedback), and excessive positive feedback with the intention of improving user experience in games or other interactive media. As demonstrated for visual juiciness and embellishments, haptic juice and HEs are shown to enhance simulations' enjoyability, aesthetic

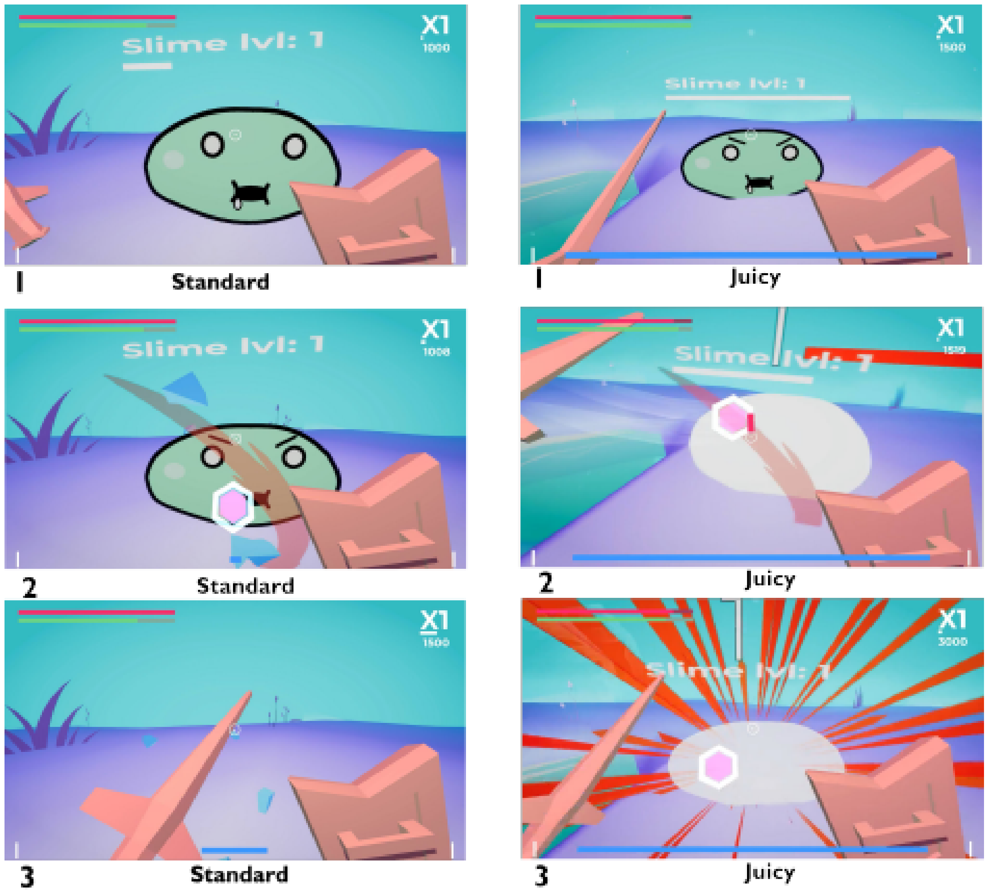

Figure 2.6: Presentation of gameplay in Dungeon Descent as the player progresses through the game (left column: standard version, right column: juicy version) developed to study the effect of Juiciness on UX by "Juicy Game Design: Understanding the Impact of Visual Embellishments on Player Experience" [23]

appeal, immersion, and meaning, having a positive impact on UX. Given their promising capabilities of complementing and enhancing visual feedback,HEs were introduced in the built prototype to reinforce the visual cues obtained when the user points toward interactable components.

These studies have indicated that the incorporation of visually engaging design elements in diverse contexts where user engagement is essential can significantly impact UX, influencing motivation, curiosity, and immersion. The intensity of these design elements can evoke positive feelings or, in some cases, become overwhelming. This study investigates these phenomena within the realm of VR simulations, specifically focusing on the communication of architectural barriers within the replicated university cafeteria and the prompted reflection on accessibility issues (see Chapter 1).

In the developed prototype, embellishments and redundant feedback serve as strategic tools to direct the user's attention toward the displayed architectural barriers and effectively convey information regarding issues and potential solutions during interactions. Chapter 6.2 reports the findings based on the experts' feedback and the effects of embellishments on UX, barriers understanding, and reflection are reported in Chapter 7.2.4.

Chapter 3

Design Requirements

This section details the methodology followed to establish the design requirements for the prototype development. The structure of the simulation is defined (see Section 3.1) and the fundamental educational features of the experience are identified and discussed on the basis of the existing literature (see Section 3.2). Furthermore, the content of the chapter delves into the assessment of the KIT campus to identify the simulation's background environment (see Section 3.3) and architectural barriers to display (see Section 3.4). The design decision concerning the embellishments and animations present in the simulation and the identification of the experiment's baseline are addressed in Section 3.5 and Section 3.6 respectively.

3.1 Structure of the Simulation

The simulation aims to compare different ways of conveying information on the issue of architectural barriers. To gather insight on the effects of embellishments, juicy design elements and animations, two versions of the experience need to be compared. The effectiveness of different communication means is assessed by dividing the simulation in two main scenes, containing the same environment with different representations of the presented architectural barriers, preceded by an introductory section of the experience to familiarise the user with the environment and its commands.
The overall simulation is therefore composed of three successive steps:

1. A tutorial, to familiarize the user with the navigation controls and interaction mechanisms. The requirement of introducing a tutorial was highlighted by the study "A Framework for the Use of Immersive Virtual Reality in Learning Environments" [22], and other general features decided based on literature suggestions can be found in Section 3.2.

2. A first scene to display the architectural barriers defined in Section 3.4 with the embellishments and animations defined in Section 3.5 . In this part of the experience, the user can explore the environment, interact multiple times with the barriers, trigger the effects and the animations, and reflect on their meaning.

3. A second scene to serve as baseline to compare result with the embellished version of the experience. As defined in Section 3.6, textual explanations were chosen as baseline and in this scene the barriers can be identified by their golden outline and the interaction only triggers the appearance of a neutral explanatory board.

All three scenes are set in the same background environment, defined in Section 3.3, to avoid confusion and facilitate comparisons between the two version of the architectural barriers' exploration process. The user will be able to switch between the experience sections by means of a simple and straightforward navigation menu that can be reached from every point within the simulation.

The steps order, when experiencing the overall simulation, was fixed. Said decision was taken to allow users to experience the barriers with the explanation conveyed via effects and animations without the previous knowledge gained from the textual boards. This was necessary to obtain specific feedback on what can be understood without explicit explanations. The section with textual boards allows then users to complete or confirm their understanding of the barriers fostering the comparison of how insight is gained from different components.

3.2 Educational Simulation Design

To establish the technology utilized in developing this project's simulation and to delineate the overall structure of the experience, we relied on the study "A Framework for the Use of IVR in Learning Environments" [22] as a foundational reference. Drawing upon the insights from this study, we assessed how the simulation's features influenced its educational efficacy and adapted the recommendations to suit the specific scope of our project (see Section 3.2.1). These considerations informed the design requirements for the simulation's structure and fundamental features (see Section 3.2.2).

3.2.1 Impact of Educational Features

To assess informativeness and understandability of the information delivery means designed and implemented in this study, guidance on the construction of educational tools in VR or similar environments was sought in the literature. Design requirements were extracted from the recommendations provided by the study "A Framework for the Use of Immersive Virtual Reality in Learning Environments" [22], and guidance in decision-making was found in the explained theories. The research paper provides a comprehensive guide for designing effective IVR learning experiences based on CTML [22] and its suggestions were deemed suitable for the scope and goal of this project.

The CTML [22] is a framework for designing effective multimedia learning environments and its three principles of learning, dual coding theory, limited capacity theory, and active processing theory, were used to support decision-making during the design phase of the prototype of this study as explained in Section 3.2.2.

3.2.2 Educational Simulation Requirements

According to the dual coding theory, people process information in two different channels, visual and auditory. Even though learning is more effective when information is presented in both ways, this study mostly investigates the visual channel, focusing on comparing different techniques. The very limited introduction of auditory queues is discussed as a limitation in Chapter 8.2.

In alignment with Limited Capacity theory [22], this prototype aims to create a simple and intuitive environment where users are informed about architectural barriers and solutions. To avoid distracting the participants or overloading their cognitive resources, the command system and the User Interface (UI) designed for this simulation are maintained as simple and intuitive as possible.

The simulation built during this study leverages interaction mechanisms and triggered effects to involve the user in the process of modifying the environment to create solutions to architectural barriers by triggering the animations, to facilitate the construction of mental models as suggested by Active Processing theory [22].

Additionally, the recommendations presented in Section 2.3 as a framework for educational simulations were adapted to the scope of this project to draw the part of design requirements concerning the experience's general structure and features. Each decision was discussed within the research group and the following conclusions were reached, defining the design requirements for the educational aspects of the simulation as listed in Table 3.1. Similarly, Table 4.1 provides an overview of the implementation decisions taken as a consequence of the same set of recommendations and a comparison with the results of this study can be found in Table 3.1.

Suggestion [22]	**Description [22]**	**Design Requirement**
“Learning first, immersion second”	On behalf of the instructional goal, it is recommended to “reduce extraneous processing” and to carefully think about the grade of immersion necessary. If a higher degree of immersion is not relevant to achieve the learning objective, here, "less is more”	Following the suggestion, the prototype of this study was developed in VR because the immersion potential was deemed sufficient even though it is lower than the one of IVR. The level of accuracy for the reproduced virtual environment was set as high to provide a realistic background and favour immersion. Simple commands and interaction mechanisms were preferred to limit distractions due to the simulation setup and aid autonomy.
“Provide learning relevant interactions”	Two recommendations are proposed to optimize learning in terms of interactions: - Avoid unneeded and learn-irrelevant interactions. - Enable the learners’ pre-training, not only in terms of basic concepts but also on how to use the interaction tools.	Interactivity was a key topic of this prototype because the users within the simulation were required to interact with the architectural barriers to discover the proposed solutions and explanations. It was decided to keep interactions to the minimum, including strictly necessary mechanics only to maintain focus on the architectural barriers. Pretraining opportunities were defined in the form of a tutorial to instruct users on the commands available during the experience and foreshadowing the interaction mechanisms present in the simulation.

"Segment complex tasks in smaller units"	Content in IVR learning environments has a high risk of overwhelming learners. Therefore, it is concluded that breaking down complex tasks into small segments is effective for managing essential processing in IVR.	To avoid overwhelming participants and to analyze the effect of each component in depth, a restricted set of three architectural barriers was presented to the participants. It was decided to divide the experience into multiple sections to facilitate orientating in the simulation structure, separated spaces for familiarisation with the commands, and exploration of concepts related to architectural barriers were designed. In agreement with the considerations made within the research group, it was decided to not have a system of tasks to evaluate the participants' capability to identify the architectural barriers using the highlighting effects and understand the accessibility issues by seeing the solutions and reading the explanations.
"Guide immersive learning"	The role of guidance is still debated. Even if there seems to be at least some agreement that completely unguided discovery learning is not useful due cognitive overload issues. The debate is about timing and form of guidance for effective learning.	In the context of this project, only experienced by experts to gather their feedback on the simulation's design and implementation choices, it was decided to provide minimal guidance. The goal was to inspect how effective and informative the embellishments and juicy design elements could be compared to textual explanations. It was decided to provide the participants with an introductory summary on the simulation purpose and structure without containing details about the visual components of the prototype.

"Build on existing knowledge"	To foster learning activities, new information should be balanced with prior knowledge to avoid under- or overstimulation. Worked examples and tutorials may help learners with a low level of prior knowledge, but hinder learners with a high level of prior knowledge. We recommend determining learners' current level of knowledge and to adjust the severity as well as the amount of support provided.	This prototype was designed to be experienced by experts in the context of buildings' accessibility to assess the informativeness and completeness of the displayed architectural barriers and the effects of the designed embellishments. Good knowledge of the topic was expected from all participants. Subtle architectural barriers and modifications were introduced among the options to evaluate how sensible to changes participants can be if they have a solid background on the topic.
"Provide constructive learning activities"	The learner's enjoyment during the IVR lesson was not diminished by adding generative learning strategies. This means that IVR has the potential to be effective for learning and at the same time makes learning more enjoyable than traditional media. We recommend providing additional constructive learning activities that enable learner's knowledge construction.	The goal of this project is to assess the appropriateness, informativeness and understandability of the developed visual means used to display architectural barriers and propose solutions. The takeaway of this suggestion is the potential of simulations as an effective teaching tool compared to more traditional means. However, the development and inclusion of constructive learning activities is outside the scope of this study.

Table 3.1: Design requirements to build an effective educational simulation [22]

3.3 Environment Design

To define the environment in which the VR simulation would take place, the impact on UX was investigated (see Section 3.3.1), the desired characteristics for the environment were identified (see Section 3.3.2), possible candidates from the KIT university campus were compared (see Section 3.3.3), and the final requirements for the implementation were defined (see Section 3.3.4).

3.3.1 Impact of the Environment

The choice of the environment to reproduce as background for the simulation was a vital design decision for the project because of its impact on the development timeline and the relatability of the experience in the virtual simulation. The impact of the background in a VR simulation is multifaceted and can significantly influence various aspects of the user experience including immersion, autonomy, relatedness, and emotional response.

The environment plays a crucial role in immersing users in the virtual world, blurring the boundaries between the real and virtual worlds, and profoundly influencing the user's sense of presence within the simulated world. Through the creation of an immersive environment characterized by realistic graphics and attention to detail, users experience a heightened sense of presence, feeling as though they are physically situated within the virtual space. This sense of presence is further enhanced by the 3D nature of VR environments, allowing users to perceive depth, scale, and spatial relationships, fostering a heightened sense of spatial awareness and immersion. The environment sets the tone and mood of the VR simulation and can additionally evoke or enhance emotional responses from users. Factors such as lighting and colour palette contribute to creating a specific atmosphere that enhances the overall experience and reinforces the intended theme or narrative. Similarly, a carefully crafted environment with appropriate ambiance, scenery, and atmosphere can elicit emotions such as excitement, awe, or fear as needed, contributing to a more compelling user experience. Facilitating active participation and exploration of the virtual environment can foster a sense of autonomy and improve the users' intrinsic motivation by contributing to the satisfaction of their needs according to SDT (see Section 2.3). On the other hand, the environment characteristics can affect the users' ability to navigate and orient themselves within the VR simulation. Clear landmarks, intuitive layouts, and effective wayfinding, together with a suitable complexity of the space for the simulation scope, help users navigate the virtual space easily, minimizing disorientation and preventing overwhelmingness.

Overall, the virtual simulation environment should be carefully designed to contribute to the participants' needs satisfaction, enhancing learning and cognitive processing within the VR simulation without obstructing the experience. Providing a suitable background that favors immersion, elicits emotional responses with a suitable atmosphere, and fosters autonomy without distracting the users is therefore paramount to create a positive VR experience.

3.3.2 Desired Characteristics of the Environment

The goal of the virtual environment, created by reproducing a real campus facility, was to serve as a neutral yet familiar background for the highlighting of architectural barriers. Commonly shared buildings were preferred over edifices belonging to single faculties for the immediate relatability and the quick understandability of the space and for the universal relevance and the representativeness of the encountered architectural barriers. Buildings belonging to specific faculties were deemed less suitable for this project because likely featuring unique and specialized characteristics that are less suitable for a comprehensive demonstration on common architectural barriers.

To contribute to immersion, the reference physical environment required features that could be accurately reproduced with sufficiently high fidelity to provide a realistic and relatable background for the VR experience. Moreover, it was essential for the environment to incorporate genuine architectural barriers of various types, offering a diverse selection of realistic challenges. By identifying and selecting architectural barriers from the real space, the VR prototype aimed to maintain fidelity to the actual environment, ensuring that the presented barriers accurately represented real-world conditions without distortion.

To promote relatability, fostering emotional attachment between the simulation participants and the environment was a fundamental aspect of this project, where users were instructed and prompted to reflect on architectural barriers in daily contexts. The created environment should represent a familiar setting for users, where they could feel as if they belong and connect with the space to be more prone to reflect on the displayed architectural barriers.

To enhance autonomy throughout the experience, the size and complexity of the chosen environment required careful consideration. It was crucial to balance providing sufficient space for meaningful exploration and ensuring that wayfinding complexities were manageable throughout the simulation. A space that was too confined would restrict participants' ability to navigate freely and explore their surroundings, hindering their discovery of the architectural barriers presented. Conversely, overly intricate architecture risked creating a disorienting and overwhelming environment, too dispersive for this project's objective and the intended duration of the experience.

3.3.3 Environment Selection Process

Having the KIT campus as a starting point for the study, a first skimming process of all the campus's facilities was needed to identify a selection of candidate buildings. The identified options would then be examined in further detail as candidates for the virtual replica in the simulation. Three buildings emerged from this initial selection process performed according to representativeness criteria (see Section 3.3.2): the KIT university's library, canteen, and cafeteria. A common property of these buildings was being shared by visitors, students, professors, and employees of all departments, as opposed to buildings that belonged to a single faculty and therefore had a more restricted audience.

Further examination of the three selected buildings led to the exclusion of the university's canteen due to its excessive size and complexity. Even though the building was known for the presence of many architectural barriers, an accurate reproduction process of both stores of the edifice was deemed too demanding and outside the project's scope. The excessive extension of the space would have diverted the user's attention from the architectural barriers, focus of the simulation, to the difficulty of navigating and orienteering within the reproduced facility, negatively affecting autonomy without contributing to other needs satisfaction (see Section 3.3.2).

On the other hand, the KIT cafeteria building had all the suitable characteristics of reasonable size and complexity. Overall, the location offered an excellent balance between the possibility of a detailed reproduction and the potential of containing a wide variety of barriers in a contained space. The library building, even though suspected of being too articulated, was retained as a candidate for further in-depth examination. It could serve as an alternative to the cafeteria if the latter proved to have unsuitable inaccessible features for the simulation's required representativeness.

The final selection process involved a comprehensive analysis of the architectural barriers within both the KIT university's library and the cafeteria which is detailed in Section 3.4.3. Given the variety and the representativeness of the barriers identified during the observational walk-through, it was clear that the KIT cafeteria was a suitable environment to be reproduced for the experience since it met the fidelity requirement while having a better size with respect to the university library.

3.3.4 Environment Requirements

In conclusion, the KIT cafeteria had the required characteristics to be a suitable background for the virtual experience. The identified design requirements and the fulfilling characteristics are summarised in Table 3.2.

Requirement	Fulfilling Characteristic
Immersion	
Reproducible with high fidelity.	Building of contained size.
Possibility to incorporate genuine architectural barriers.	Hosting a representative collection of architectural barriers.
Emotional Connection	
Relatability	Shared by all faculties on campus. Frequented by university's students and staff.
Autonomy	
Space for meaningful exploration.	Availability of multiple and very different areas.
Ease of navigation.	Distribution on a single floor. Possibility to clearly delimit the navigable area.

Table 3.2: Design requirements for the environment of the VR simulation

3.4 Architectural Barriers Design

To define the architectural barriers that would be represented in the VR simulation, insight was drawn from the literature (see Section 3.4.1), the desired characteristics for the architectural barriers were identified (see Section 3.4.2), a pool of candidate accessibility issues was sought (see Section 3.4.3), and experts feedback was collected to validate the findings (see Section 3.4.4) and concur to the definition of the final requirements for the architectural barriers (see Section 3.4.5).

3.4.1 Impact of the Architectural Barriers

The choice of the architectural barriers to be reproduced within the virtual environment provided many possibilities and multiple different approaches could have been applied. The number of accessibility issues to display, the variety of disabilities to address, the positioning of the barriers within the environment, and the specifics of each issue representation were some of the decisions required for the prototype design. The main concern was guaranteeing the highest comprehension possible for the general topic of accessibility while conveying precise information on the specifics of each architectural barrier. Additionally, for the goal of this study, analysing the impact of different components on understanding meant that multiple variations and possibilities had to be included in the prototype so that their effects could be later compared.

The architectural barriers play an important role in affecting the participants' interaction, immersion, and imagination during the VR simulation since the objects representing the accessibility issues are the main interactive components of the prototype. Learners would gain knowledge about accessibility by actively engaging with the experience components as suggested by the Active Processing Theory (see Section 2.3) and therefore, designing suitable architectural barriers and carefully choosing their design characteristics was paramount to this project's goal. Additionally, as suggested by Limited Capacity Theory (see Section 2.3), the architectural barriers selection had to consider not overloading learners' cognitive resources to optimize the effectiveness of the learning experience.

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Further considerations and decision-making on how the impact of Active Processing Theory and Limited Capacity Theory defines the desired characteristics of the architectural barriers for this prototype are detailed in Section 3.4.2

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3.4.3 Architectural Barriers Scouting Process

Once the KIT university cafeteria was chosen as target building for the reproduction as virtual background for the simulation (see Section 3.3.4), the screening process of the area led to the identification of a wide variety of barriers. During the examination of the facility, different factors were involved in the process of identifying barriers. Different disability groups, as well as various times of the day, and varying weather conditions, were considered during the scouting process.

The list of architectural barriers present in the cafeteria was initially filled with the issues I identified by applying the observational walk-through method [10]. Additionally, I compared the facility's features, pathways, and furniture with the accessibility guidelines provided by the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUB) [16] to improve and complete the list of barriers. The document used during the observational walk-through can be found in the appendix (see Appendix A) and is an improved version of the checklist presented in the paper "Architectural Barriers to Persons With Disabilities in Businesses in an Urban Community" [1].

The identified list of barriers served as a starting point for the definition of the issues to include in the final version of the simulation. Additionally, expert validation (see Section 3.4.4) was used to confirm the correctness of the identified barriers, provide additional insight, and define the final subset of relevant barriers for the VR experience.

3.4.4 Experts Validation

The collection of expert feedback was used to validate the findings of the previous step (see Section 3.4.3) and to select a set of barriers suitable for the simulation (see Section 3.4.5). The goal of the questioning was to gather some additional insight on barriers of unclear nature, to have some direct feedback on the correctness of the identified issues, and to define their relevance for the simulation. Two experts were involved during this phase of the requirements definition, each competent in different and complementary aspects of this study.

The first expert involved, called ExpertA for the purpose of this chapter, is an Architecture Professor and researcher at Karlsruher Institut für Technologie (KIT). The expert's research and lectures focus on the creative potential of design choices to meet the complexity and diversity of people's needs, studying architecture and design for the well-being and inclusion of all people as a natural component of sustainability. ExpertA was also involved in the validation of the resulting prototype at the end of this study (see Section E1 in 6.1). The expert's familiarity with VR simulations allowed discussing features of the simulation that concurred in the definition of the design requirements (see Section 3.4.5).

The second expert interviewed, referred to as ExpertB during this chapter, is the Karlsruhe Student Union representative for disabled students. ExpertB is responsible for finding accessible and inclusive solutions in the context of the services provided by the Student Union on campus. Their familiarity with the issues existing in the building where the cafeteria is located allowed the collection of precise insight into the entity and relevance of the architectural barriers highlighted during the screening process. I analysed and discussed the architectural barriers identified during the screening process with ExpertB during a visit to the university cafeteria. The collected information was used to identify the selection of architectural barriers to integrate into the final version of the simulation (see Section 3.4.5).

Questionnaire Overview

A questionnaire was used for guidance when collecting feedback on the architectural barriers in the KIT cafeteria that could be represented inside the virtual simulation. The questions presented to the experts covered four main topics, discussed in broader or less details depending on the individual's background and field of expertise:

1. Clarifications on some barriers identified during the cafeteria walk-through.

2. Discussion of the simulation's requirements with focus on specific disability groups.

3. Discussion of accessible alternatives and equal treatment.

4. Discussion of information retrieval issue.

The first topic covered some practical doubts that emerged during the walk-through when the literature was not deemed sufficient to declare the specific design choices and implementations as architectural barriers. Further insight was gathered on:

- The building's accessibility by means of public and private transportation.
- The impact on accessibility of the bicycles' positioning in the area surrounding the cafeteria.
- The slope and the termination at the door of the outside tilted area.
- The draining capabilities and the skid resistance of the flooring material in the external area.
- The impact of stairs that lack the high-contrast, non-slippery stripes that mark the rise and tread of the first and last steps.

The second section investigated the relevance of the requirements for the simulation's purpose, focusing on each disability group and their specific needs. The aim of the questions was to gather information coming from the experts' direct experience, going beyond the limitations of the analysed literature. The expert's perspective was obtained on:

- The suitability of the chosen building related to other options (e.g., the cafeteria instead of the canteen or the library)
- The effects of weather seasonality and times during the day on the building's accessibility.
- The effects of crowd levels for different disability groups.
- The barriers with higher relevance for the VR simulation.
- The relevance of cognitive disabilities in a university environment.
- The accessibility barriers specifically for neurodivergent individuals.
- The accessibility of the cafeteria facility for people with hearing impairments.

The third part of the questionnaire explored the ethical issue related to the balancing of equal treatment and tailored solutions. Specific and controversial examples found in the KIT cafeteria were brought to attention, providing concrete situations to discuss. In particular, the discussion probed:

- The controversies of accessibility solutions when simultaneously addressing multiple disability groups.
- The inclusion perception when accessible options are available, but don't correspond to the most used option.
- The feeling of restricted access to disabled restrooms.
- The trade-off between flexibility and universality when providing multiple options with different complementary features.

The fourth section dug into the orientation and guidance systems issue. The literature only provides general information and tailoring it to the specific case requires on-field experience. Insight was gathered on:

- The kind of indication system that would help people with visual impairment navigate an unknown building without requiring any assistance.
- The difficulty of finding alternative accessible pathways in case of inaccessible doorways/thresholds for disabled people.
- The issue of choosing goods in the cafeteria without someone else's support if no tactile labels are available.
- The need for tactile paths inside and outside the building.
- The difficulty of recognizing a room's purpose if no tactile or auditory description is available.

Particular space during the semi-formal interviews was given to the experts' personal opinions as complementary insight with respect to the formality of the investigated literature.

Feedback from ExpertA

ExpertA field of expertise covered the usage of disability simulations to educate architecture students about barriers, but they were not familiar with the specific accessibility features of the interior area of the KIT cafeteria environment, chosen as the virtual background for the simulation. Particular attention was given to the discussion of the architectural barriers present in the exterior area surrounding the cafeteria, to the discussion of the relevance and suitability of the issues as candidates to be represented in the prototype, to the suggestion of underestimated issues, and to the highlighting on examples of contrasting solutions for different disability groups. The four topics and the summary of the findings is reported in the lists below. Accessibility of the external area of the cafeteria:

- The bicycles' positioning without any tactile delimitation of the dedicated areas is a relevant issue. Hazards can be created, especially for blind and visually impaired people.
- The tilted area next to one of the entrances has a good drainage system, but the slope is too steep to be comfortable for people with motor impairments. It was highlighted, on a general note, that the possibility of having different levels of fitness and strength for people in this target group, needs to be accounted for. The accessibility ramp should be present, but also soft enough to be accessible to everyone.
- The outside flooring condition, contrary to the interpretation gained from the literature review, is not regular enough for wheelchair users. Especially in winter, with snowy and icy conditions, the dips and rises in the external paving can increase the difficulty of wheelchair users when autonomously reaching the facility.

Relevance of features for the simulation:

- The expert confirmed that the choice of the cafeteria environment was proper for the purpose of the study because representative of the common architectural barriers encountered during people everyday lives.
- Related to the seasonal weather conditions it was highlighted that:
  - During winter season, the snowy and icy conditions can make the external areas difficult to navigate when using wheelchairs or walking-aids.
  - During summer season, the presence of many windows allows the natural light inside, but that can increase the heat of the interior spaces. The excessively warm condition can be a problem for people with heat sensitivity.
- The presence of crowds can be impairing when navigating inside the building, especially for wheelchair or walking-aids users. In addition, the presence of crowds causes an increase in the background noise levels. The increased noise can be very tiring, negatively affects: people subject to sensory overload, blind or visually impaired people that mainly rely on auditory cues for communication, and people with auditory impairments that struggle in noisy environments.
- The simulation could highlight both traditional intuitive barriers that are easy to recognise (e.g., accessibility ramps), and more subtle issues to prompt reflection on the variety of existing architectural barriers. It was suggested to include different target groups in the simulation.

- The presence of visually and tactilely contrasting markings of the steps is very important. It allows visually impaired and blind people to detect the stairs in time. The effect of their absence for accessibility should not be underestimated because it can constitute a relevant risk of hazards.

Underestimated issues for different target groups:

- Neurodivergence is rarely accounted for in building design.
- Background noise during rush hours is an issue for people with auditory impairments because it can make communication difficult and unnecessarily tiring. In addition, the acoustics of an environment can be negatively affected by windows, present in large amounts in the coffee shop.
- Non-linear settings have a positive impact on accessibility for auditory impaired people. The presence of round tables in the coffee shop is an asset for users with auditory impairments. In fact, it allows people to face each other, facilitating lip reading and gesture recognition during conversations.
- The required brightness level of an environment for visually impaired people is way higher with respect to the one for normally sighted people. Therefore, the usage of dim lights can contribute to the creation of a welcoming and relaxing environment, like the university cafeteria, but constitute a barrier for visually impaired customers.
- A common issue when highlighting elements that can cause hazards in a way that makes them easily identifiable is the usage of bright colours. The excessive highlighting risks to reverse the visual hierarchy that can lead the user to identify safety concerns as landmarks or points of interest, causing disorientation within a space.

Contrasting effects of accessibility measures:

- The usage of volumetric tactile patterns and guiding lines, which is an asset for blind people but an obstacle for wheelchair users and people with motor impairments who prefer smooth surfaces.
- the presence of windows that improves the visibility within an environment but increases the risk of overheating spaces in warm seasons, creating an issue for people with heat sensitivity.
- The lighting level of an environment could be insufficient or too strong for people with different visual impairments, or subjected to sensory overload.

- The muffling of superfluous sounds in an environment, like the scratching sound of chairs on the floor, can help reduce the background noise level improving the experience for people with auditory impairments or noise sensitivity. The same strategy causes the removal of an environment's characterizing sounds that can be used by blind people in identifying the purpose of a space.

Feedback from ExpertB

With the second expert, representative for disabled students at the Karlsruhe Student Union, the architectural barriers found during the screening process of the KIT cafeteria were discussed at length and all the issues and accessible options were evaluated and compared. No direct feedback was obtained on the suitability of barriers for the VR simulation because the topic was outside of the expert's field of expertise.

ExpertB agreed with most of the highlighting, even though it is rare that accessibility issues are reported. On many topics he had never received complaints and, even though he agreed with the limitations presented, in most cases he couldn't add confirmations from personal experience. Thanks to the intervention of the expert, the previous detailed analysis of the architectural barriers on the facility obtained from the literature review and the walkthrough can be considered accurate and complete.

Different information, with respect to what was previously gathered, was given regarding the accessibility of the bathroom for disabled. The room was thought to be inaccessible because locked with a key that needed to be asked for, but it was explained that it is instead inclusive because it can be opened with a European Key. The key can be requested by disabled people and grants them access to all the barrier-free restrooms that adhere to the initiative.

In comparison with the feedback gathered from ExpertA, ExpertB believes that the bright orange colour used for the structural pillars present in the KIT cafeteria could be misleading in terms of orientation but should not be changed. In fact, the pillars cannot be removed and it was underlined how the customers' safety should be the first concern and the pillars colouring contributes to making them very visible, protecting people from hazards.

Additional insight was given on the safety issues that exacerbate the importance of some of the barriers. In particular, the two staircases that connect the cafeteria to the external area are not accessible, meaning that people using wheelchairs or walking aids could follow those evacuation paths and remain blocked at the staircases while everyone else is leaving the building. This safety issue that discriminates against people with motor impairments was highlighted as very relevant problem by ExpertB during the evaluation of the proposed barriers.

3.4.5 Architectural Barriers Requirements

From the barriers scouting process (see Section 3.4.3) a pool of possible accessibility issues was identified. From the insight gained from the literature (see Section 3.4.2) and considerations within the research group, representing three very different architectural barriers and reporting solutions as a consequence of interaction were decided on. From the feedback obtained from the experts (see Section 3.4.4), additional considerations on the nature of the architectural barriers' selection were extracted and the final three examples were defined.

Following the suggestions provided by ExpertA (see Section 3.4.4) on the prototype's features it was decided to:

- Confirm the choice of the cafeteria as background environment.
- Cover more than one disability within the prototype.
- Include both intuitive and more subtle barriers.
- Involve accessibility issues that had a clear and reproducible solution.

From the pool of architectural barriers identified and taking advantage of the insight provided by ExpertB (see Section 3.4.4), the three following issues were selected to be represented in the simulation:

- The too-tall display device used to upload money on the card needed to pay on the premises.
- The inaccessible staircase that lacks an accompanying ramp as a step-free alternative.
- The insufficient luminosity level of the environment that prevents most visually impaired individuals from optimally using their residual vision.

The stand-up display, identified as the first barrier for the simulation, is used to upload money on the university's card that is used to pay for purchases within the premises. The accessibility issue of the device is the touchscreen display positioning [16]. Its height is not accessible to people in wheelchairs because the commands are unreachable. The specific choice of installing a tall display, instead of a lower or adjustable one, forces people in a sitting position to struggle, ask for help, or use the lower one present in a different area of the building only accessible via outdoor connections.

The inaccessible staircase, chosen as the second barrier for the prototype, can be found multiple times in the KIT cafeteria when two different levels need to be connected. A stairway cannot constitute an accessible vertical connection on its own, even though it can be safely used in part by people with motor impairments as well as blind and visually impaired individuals. The absence of accompanying ramps or lifts, though, makes the stairs inaccessible to wheelchair users and in part to people with limited mobility [16].

The lighting level of the interior areas, chosen as the third barrier for the prototype, is a crucial feature of a building, having a big impact on accessibility for visually and auditory impaired people. In interior spaces, it is essential to prioritize adaptable and cost-effective lighting systems [16]. Given the significant variation in illumination needs among individuals with different disabilities, customizing light levels can greatly enhance the accessibility of the cafeteria's sitting areas.

The specific choices allowed covering, as involved disabilities, the widely known motor impairment and wheelchair usage, and the less commonly acknowledged visual impairments. As suggested by ExpertA, the necessity of a ramp was chosen as an example of an intuitive barrier, while the display's excessive height and the insufficient environment brightness served as more subtle examples. The option of the inaccessible stair was also included because of the safety issue discriminating against people with motor impairment brought up by ExpertB. In addition, the selected group of barriers contains both issues related to furniture choice and structural elements of the building.

For each barrier, a well-defined solution to be displayed in the simulation was identified:

- The too-tall display would be shrunk to reach a 1.20m height, accessible from a sitting position.

- The staircase would be partially substituted by a ramp to show the integration of the two options.

- The insufficient brightness of the environment would be highlighted by the presence of a book on one of the studying tables and the contrast in the writing would be increased to show the necessary level of brightness needed to read.

The possibility of incorporating a crowd into the simulation, whether as a barrier example or to enhance the environment's sense of relatedness, was ultimately dismissed due to time constraints. Instead, the priority was placed on creating a more straightforward and navigable environment. This decision is acknowledged as a limitation of the project, and its implications are discussed in Chapter 8.2.

The representation of the architectural barriers and the explanations of the accessibility issues in the final version of the prototype can be seen in Section 4.

3.5 Effects Design

To define the requirements of the embellishments and juicy design elements in traduced in the first section of the simulation, their impact on UX was analysed (see Section 3.5.1), the desired outcome was investigated (see Section 3.5.2), and the features for each effect and animation were assigned (see Section 3.5.3). The describe process led to the identification of the design requirements detailed in Section 3.5.4.

3.5.1 Impact of Effects on Player Experience

VEs and juicy design elements play a crucial role in shaping the overall UX in VR environments. As suggested by "Juicy Game Design: Understanding the Impact of Visual Embellishments on Player Experience" [23], VEs significantly enhance the aesthetic appeal of games, contributing to their visual attractiveness and improving user engagement. These elements add visual interest, spark curiosity, and deepen immersion in the virtual world, ultimately leading to a more engaging and enjoyable experience. While the impact of VEs on objective user performance may be limited, they enhance perceived competence and mastery, further enriching the UX.

Juiciness was also found to improve user experience [25] in terms of visual appeal, curiosity, immersion, and meaning. While juiciness may not significantly influence user performance, it enhances the overall UX by providing immediate and abundant feedback, reinforcing perceived competence, and improving engagement, satisfaction, and information retention. Moreover, juicy design, amplifies the UX by providing immediate and gratifying responses to user actions.

Similarly to VEs and juicy design elements, Juicy haptics, also known as vibrotactile embellishments, can enhance enjoyability, aesthetic appeal, immersion, and meaning in games [27]. High haptic juice can improve visual stimuli and enhance UX, even though the difference between low and high juicy haptic conditions on UX constructs may not be significant.

Therefore, including VEs, animations, and sound effects, have potential in captivating users' attention and enhance engagement by making interactions feel dynamic and more exciting. These elements contribute to user satisfaction by creating a sense of accomplishment and reward, reinforcing user motivation during the experience, and enhancing immersion by making interactions more meaningful. Since VEs and juicy design elements proved to have a profound impact on various components of the UX in VR environments, they were leveraged in this project to investigate how they could affect an educational experience about accessible building design.

3.5.2 Desired Outcome of the Effects

As discussed in Section 3.5.1, embellishments and juicy design enhance aesthetics, immersion, engagement, curiosity, and perceived competence and create a more compelling and enjoyable experiences for participants. In this project, VEs and compelling design elements were introduced in one section of the experience to analyse how they affect UX in a simulation that sensitises and educates about architectural barriers. Different objectives were addressed, and multiple embellishments were designed to meet the goals of improving UX and fostering reflection.

To improve the simulation's aesthetic appeal, with respect to a bare version of the experience, coordinated effect reflecting a unified theme were designed. The colours were chosen to match the atmosphere of the environment while creating visible effects. Slight differences while maintaining the theme were introduced to gather feedback on participants preferences.

To enhance immersion, realistic modifications of the space were designed as solutions to the presented architectural barriers with some degree of variation on accuracy of the displayed solution. The represented barriers and solutions reflected real issues encountered in the physical environment that was reproduced in VR, creating continuity between the background and the animated architectural barriers. Different accuracy levels in the represented solutions were designed to investigate the level of abstraction acceptable to convey information without resulting too complicated and confusing.

To promote engagement, mechanisms were designed to trigger animations and effects when the user interacted with the architectural barriers. The goal was to alternate the presentation of accessibility issues and solutions upon interaction with the barriers to favour understanding of the issues. Additionally, multiple effects were added to the animation in order to understand their impact on the participants' understanding and enjoyment of the experience as well as desire to prosecute with the interactions. Variations in the animations' speed and complexity and in the effects visibility and dominance were introduced to gather insight on the participants reaction to the different combinations.

To foster curiosity towards the architectural barriers, a captivating highlighting mechanism was designed. The goal was to draw the participants interest and attention towards the interactable objects of the experience and direct their movement towards them.

Perceived competence is affected by the informativeness and clarity of the redundant feedback provided. Highlight mechanisms and effects triggered upon interaction were designed to support user understanding of the events while the animations displayed how accessibility issues could be solved.

3.5.3 Effects Characteristics Definition

The visual effects designed for the embellished scene of the simulation can be grouped in two categories: highlighting effects and interaction triggered effects.

For the highlighting of the architectural barriers, two mechanisms were designed to address the impact on understandability and visual appeal of different options. The first highlighting technique consisted of a simple yet straightforward outline that would delineate the architectural barriers demarcating them from the background. Said highlighting was applied to all interactable objects within the simulation, including elements in the tutorial and barriers in the barer version of the experience used as baseline, to guarantee uniformity and basic recognisability of interactive elements. The second highlighting mechanism was designed to be more articulated and captivating, contributing to the participants engagement and curiosity towards the highlighted architectural barriers. Said mechanism needed to be visible from a distance but it was decided to make the effect disappear once the user was in the target's proximity to favour concentration on the architectural barriers and triggered solutions.

For the effects triggered upon interaction, multiple senses were involved. Vibrations of the controllers were designed as haptic feedback to signal when hovering or selecting the architectural barriers, while auditory cues were designed to accompany the visual effects when the animation was triggered. It was decided to introduce simple and uniform auditory feedback to focus the research on the effect of visual cues; this decision is discussed as a limitation in Chapter 8.2. As visual effects, many possibilities presented themselves and two contrasting effects were chosen to investigate the participants preference on effects density, extension, and speed. The first effect designed consisted of a contained explosion-like particles system placed in the centre of each architectural barrier and triggered upon interaction. The second effect presented instead opposite characteristics, being a slow raising snow particle system that would occupy the whole user's field of view.

For the animations, multiple variables were identified, and different possible combinations were tested and presented to the user to evaluate their impact on comprehension and engagement. Complexity and speed, visibility, and size of the spatial change, along with precision of the displayed animation were the addressed characteristics of the architectural barriers' animations. The following combinations were decided on to be applied to the three selected barriers (see Section 3.4.5). The first architectural barrier, consisting of the tall display device, would have a fast and complex animation of the solution while carrying a small spatial change between the initial and final stage of the height modification. The second architectural barrier, consisting of the low readability book, would carry a fast yet simple animation with no spatial change or size modification of the interactable object since only the contrast of the pages would be modified. The third architectural barrier, the inaccessible staircase, would instead display a slow and simple modification with a very visible spatial modification consisting of the ramp appearance as solution introduction. Different level of accuracy for the displayed solutions were designed so that understandability of the concepts could be examined depending on the precision of the solution. In fact, a very precise but small modification that would solve an accessibility issue might be difficult to spot by participants with reduced background on the topic, while, on the other hand, an exaggerated solution might be inaccurate but easier to understand at a general level.

3.5.4 Embellishments, Juiciness and Animations Requirements

This section summarizes the design decisions taken for the effects and the animations introduced in the embellished scene of the experience. The different combinations were designed to investigate the effect of multiple variables applied to embellishments while maintaining a contained length of the experience suitable to collect reliable feedback on details. Table 3.3 details the requirements for the effects triggered upon interaction with the architectural barriers, Table 3.4 contains the final requirements for the highlighting effects, and Table 3.5 explains the characteristics defined for the animations that display solutions to the accessibility issues.

Effect	**Design Requirements**
Auditory Effect	Simple, blunt, and neutral auditory cue to suggest that interaction occurred. Applied to all architectural barriers.
Haptic Effect	Short and subtle controller vibration when hovering interactable objects. More decisive and vibration of longer duration upon interaction. Applied to all interactable objects.
Concentrated Visual Effect	Fast explosion-like effect. Small size compared to the architectural barrier. Central placement with respect to the architectural barrier. Applied to two architectural barriers: too-tall display device and inaccessible staircase.
Distributed Visual Effect	Slow raising snow like effect. Low density particle system that is distributed over the user's whole field of vision. Applied to one architectural barrier: low contrast book.

Table 3.3: Design requirements for the simulation's effects that are triggered upon interaction with the architectural barriers

Effect	Design Requirements
Simple Highlighting	Outline that delineates the interactable object. Visible colour to demarcate the object from the background. Applied to all interactable objects of the simulation, included the ones within the tutorial and the scene without embellishments.
Articulated Highlighting	Articulated effect that encases the architectural barrier. Visible from a distance and deactivated when the user moves closer to the target.

Table 3.4: Design requirements for the simulation's highlighting effects

Effect	Design Requirements
Display Animation	Complex and fast animation simulating a shrinking size spell cast on the object. Small spatial change consisting of a contained height resize. High fidelity of the transformation to the accessibility guidelines [16].
Book Animation	Simple and fast animation that suddenly changes the contrast of the book's pages improving readability. No spatial change since the architectural barrier does not move nor changes size. Medium fidelity of the transformation to the accessibility guidelines [16] since the required contrast for visually impaired individuals can vary greatly.
Staircase Animation	Simple and slow animation simulating an accessibility ramp being drawn from the staircase. Remarkable spatial modification consisting of a big ramp's appearance. Low fidelity of the transformation to the accessibility guidelines [16] since a realistic ramp would not fit the available space.

Table 3.5: Design requirements for the simulation's animations that display solutions to the architectural barriers

3.6 Baseline Design

Establishing a baseline for an experiment is fundamental to evaluate the effects of interventions or manipulations. It represents a fundamental and neutral condition that allows isolating, examining, and comparing the specific effects of each intervention serving as a reference. For this project, the baseline serves as the comparison point for assessing the effects of different embellishments and juicy design elements introduced within the VR simulation. In fact, by establishing a baseline, it is possible to systematically investigate how variations in the VR experience influence participant behaviours and responses. This approach enables us to disentangle the specific contributions of different elements within the experience and discern their individual effects on UX and reflection.

In order to achieve this goal, it is essential to select a baseline that is as neutral and unbiased as possible. One potential baseline approach considered for this project involved simulating disabilities within the VR environment, and, as an alternative, the introduction of textual explanations was considered. The following section (see Section 3.6.1) explores the rationale behind selecting textual explanations as the baseline for this project, as well as the implications and limitations of this decision.

3.6.1 Baseline Selection Rationale

The first baseline option to be investigated was the introduction of disability simulations. Building a simulation where participants would experience the feeling of being visually impaired or sitting in a wheelchair while moving within the virtual environment was considered due to its wide past applications (see Section 2.1). This approach, while seemingly intuitive and potentially supportive of insights gleaned from existing literature, posed significant drawbacks. While it might prompt reflection, the distortion introduced by simulating disabilities could lead participants to draw inaccurate conclusions, remaining unaware of the biases introduced by the simulation and potentially contaminating the project's results, particularly when reflection was addressed. Given the extensive literature highlighting the controversial negative effects of simulating disabilities to raise awareness about accessibility issues (see Section 2.1), this option was ultimately deemed unsuitable, and an alternative was sought.

A possible baseline alternative evaluated within the research group consisted of the introduction of textual explanations. In this version of the simulation, the accessibility limitations would be highlighted in the environment, but the issues and the necessary modifications would be explained employing textual boards. An experimental study on the effect of summarizing scaffolding and textual cues on learning performance [28] suggests that the introduction of written information can positively influence a VR learning experience. Textual cues in particular are shown to improve the participants' learning performance and mental model without increasing their cognitive load. These cues, presented as detailed explanations, enhance learners' processing and facilitate information selection and memorization. Since further literature on this or other methods to consider was not found, and textual explanations had the potential of being neutral and unbiased, they were deemed a suitable and promising baseline option and were therefore adopted. This decision and the limited literature background behind it are discussed as a limitation in Chapter 8.2.

3.6.2 Baseline Requirements

Textual explanations were chosen as a baseline for this project for their simplicity, potential neutrality, and possible absence of bias. To reach that objective it was decided to introduce textual boards within the simulation in correspondence of the architectural barriers. Upon interaction with the barriers, the explanations would appear for the user to read. Each explanation would contain a title with an indication of the accessibility issue and a description of further details, potentially introducing new insight that could not be conveyed by means of the animations.

Concerning the textual boards' aesthetics, a visible background colour and contrasting writing were used for the headline, while the main explanation was kept black on a very light blue background that matched the atmosphere of the environment. The goal of the colour choice was to provide good readability while maintaining the colour palette used within the simulation.

It was decided to maintain the textual explanations content concise and relatively short, to provide insight on the accessibility issues without giving the participants too much to read. Feedback on the decision to introduce textual explanations and on the amount of reading required can be found in Chapter 6.2.2, where Thematic Analysis (TA) was used to extract patterns from the experts' opinions on the simulation.

Chapter 4

Implementation

This section describes the process of developing the VR simulation. While not directly relevant to answering the research questions, understanding the used technology and the implementation process can be helpful when contextualising the results of the evaluation (see Chapter 6).

4.1 Technologies

This section highlights the technologies employed in the development and testing of the VR simulation. The VR environment was constructed using Unity, a renowned game development platform, along with several integrated packages tailored to enhance the user experience and streamline development. These packages include ProBuilder for 3D modeling, XR Interaction Toolkit for managing user interactions, and XR Device Simulator for facilitating testing without continuous reliance on the Meta Quest 2 headset.

The main hardware component consisted of the Meta Quest 2, the VR head-mounted display (HMD) shown in Figure 4.1 that is worn by the user to experience the simulation. The HMD is accompanied by two controllers and the VR glasses, secured to the user's head by means of straps. A system of sensors and buttons allows following the user's movement and collecting the inputs to accurately reproduce them within the VR environment.

Additionally, a personal laptop was used to run and supervise the simulation during the experiment to collect the experts' feedback.

The software components include both the development environment and the used plugins. The VR environment was developed in Unity with the aid of ProBuilder, XR Interaction Toolkit, and XR Device Simulator as imported existing packages.

Unity is a standard game-developing platform, which was chosen because of

Figure 4.1: Meta Quest 2 head-mounted display used for VR simulations

its popularity, flexibility, and compatibility with most devices. The possibility of building a project for Android devices was a crucial feature because it was necessary to deploy the simulation on the Meta Quest 2 headset.

ProBuilder is a Unity plugin for 3D modeling. It was chosen to substitute the initially considered Sketch-Up because the latter is not supported by Unity anymore. An important advantage of ProBuilder, with respect to most popular alternatives like Blender, is its similarity with Sketch-Up, its ease of use, and its optimization for simple geometry. The plugin was used to build the architectural structure of the coffee shop, including the walls of the building, the doors and windows, and part of the furniture.

The XR Interaction Toolkit is the standard library to handle the interaction between the user and the simulation. It provides a structured and standardized set of components that can be used to create an XR user and to handle the interactions with the objects in the surrounding simulation.

The XR Device Simulator is another plugin useful to support the development of XR simulations because it transfers the inputs received from the mouse and keyboard to the simulation as if they were produced by the headset and controllers' set. This feature allows quick testing of the simulation during the development phase without the need to have the Meta Quest 2 always handy. Additionally, the possibility of having an alternative is beneficial because prolonged and intermittent usage of the headset can cause motion sickness.

4.2 Construction of an Educational Simulation

The implementation of the prototype simulation followed the design requirements defined to build an effective educational simulation [22]. Table 4.1 reports how the design requirements for an educational simulation shown in Table 3.1 were converted into implementation components of the simulation. Further detail on how the mentioned elements were created and their final look in the simulation are presented in the following sections.

Suggestion [22]	**Description [22]**	**Design Requirement**
“Learning first, immersion second”	On behalf of the instructional goal, it is recommended to “reduce extraneous processing” and to carefully think about the grade of immersion necessary. If a higher degree of immersion is not relevant to achieve the learning objective, here, "less is more”.	The simulation was developed in VR (see Section 4.1). The cafeteria building was accurately reproduced to maintain the same spaces, features, and atmosphere of the real environment (see Section 4.3). The command system was implemented to maintain the highest possible natural feeling, preferring Continuous Movement to other navigation mechanics, while the Ray Interactor was chosen as interaction mechanisms for its intuitiveness (see Section 4.4).
“Provide learning relevant interactions”	Two recommendations are proposed to optimize learning in terms of interactions: - Avoid unneeded and learn-irrelevant interactions. - Enable the learners’ pre-training, not only in terms of basic concepts but also on how to use the interaction tools.	Interactions were limited to the three architectural barriers present in the environment and the navigation menu used to move across different scenes within the simulation (see Section 4.5). The tutorial (see Section 4.6) was implemented as the first scene of the simulation presented to the participants. Here users could familiarise themselves with the navigation system and the interaction mechanisms, along with getting a first impression of the simulation environment to allow focusing on the architectural barriers at later stages of the experience.

"Segment complex tasks in smaller units"	Content in IVR learning environments has a high risk of overwhelming learners. Therefore, it is concluded that breaking down complex tasks into small segments is effective for managing essential processing in IVR.	Three separate sections of the experience were implemented to have a tutorial first (see Section 4.6), followed by two successive scenes were architectural barriers and solutions are displayed with animations and embellishments first (see Section 4.7) and textual explanations of the issues are presented later (see Section 4.8). Keeping the concepts separated allowed comparing the effects of each component and divided the overall experience in smaller, more manageable, sections suitable for the participants attention span.
"Guide immersive learning"	The role of guidance is still debated. Even if there seems to be at least some agreement that completely unguided discovery learning is not useful due cognitive overload issues. The debate is about timing and form of guidance for effective learning.	An introductory panel is presented to the participants right at the beginning of the experience before accessing the menu and the tutorial (see Section 4.5). The introduction is the only form of indication present in the simulation, in addition to the self-explanatory menu used to navigate between the simulation's scenes. Participants are instructed to find the three architectural barriers displayed in the environment and interact with them. The informativeness of the highlighting techniques was part of this project's investigation and therefore no additional guidance was provided during the simulation.

"Build on existing knowledge"	To foster learning activities, new information should be balanced with prior knowledge to avoid under- or overstimulation. Worked examples and tutorials may help learners with a low level of prior knowledge, but hinder learners with a high level of prior knowledge. We recommend determining learners' current level of knowledge and to adjust the severity as well as the amount of support provided.	This suggestion only impacts the design phase and does not affect the prototype implementation. Nevertheless, the information presented in the bare scene of the experience was balanced to provide more obvious and more subtle insight to investigate the effect of different detail levels (see Section 4.8).
"Provide constructive learning activities"	The learner's enjoyment during the IVR lesson was not diminished by adding generative learning strategies. This means that IVR has the potential to be effective for learning and at the same time makes learning more enjoyable than traditional media and we recommend providing additional constructive learning activities.	This suggestion only impacts the design phase and does not affect the prototype implementation.

Table 4.1: Implementation decisions to build an effective educational simulation [22]

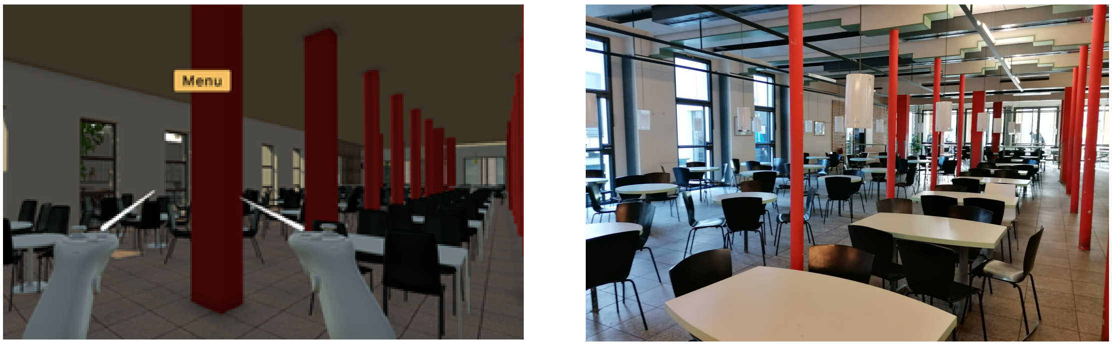
4.3 Construction of the Environment

As specified by the design requirements for the simulation environment (see Section 3.3.4), the KIT cafeteria building of the KIT campus was to be reproduced with accuracy and attention to detail, recreating the different areas contributing to the space. Figure 4.2 shows the spaces reproduced and connected to recreate the cafeteria area of the overall building and Figures 4.3, 4.4, 4.5, 4.6, and 4.7 show the result of the reproduction process, comparing the virtual and physical versions of the different cafeteria areas.

Figure 4.2: Environment of the simulation reproduced from the architectural plan of the KIT cafeteria

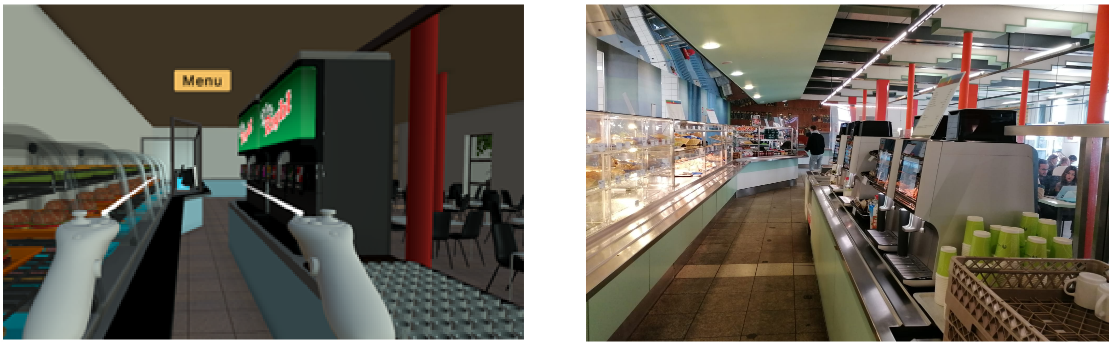
(a) **(b)**

Figure 4.3: Study area of the KIT cafeteria in (a) the virtual and (b) the physical versions.



(a) **(b)**

Figure 4.4: Main sitting space of the KIT cafeteria in (a) the virtual and (b) the physical versions.



(a) **(b)**

Figure 4.5: Food and drinks purchase space of the KIT cafeteria in (a) the virtual and (b) the physical versions.

To define the boundaries of the navigable space in a way that autonomy was enhanced (see Section 3.3.2), it was decided to use the building's walls as delimitation, including all the interior spaces in the reproduced parts of the facility. As a consequence, the exterior space, examined for barriers detection during the design phase, was not accurately reproduced during the implementation phase. For completeness and relatability (see Section 3.3.2), a background for the environment was created, giving the impression of an existing external area outside the building visible from the windows. However, the user was not allowed outside.

Reproducing the KIT cafeteria environment to serve as background for the simulation was a time-consuming step of development. As stated in the design phase, particular emphasis was given to including details from the real building,

(a) **(b)**

Figure 4.6: Chill Out space of the KIT cafeteria in (a) the virtual and (b) the physical versions.

(a) **(b)**

Figure 4.7: Inner outside area of the KIT cafeteria in (a) the virtual and (b) the physical versions.

including the choice of accurate materials and precise furniture replication. The aim was to contribute to the UX by creating a realistic, friendly, and immersive environment with which the user could easily connect.

To accurately replicate the cafeteria and maintain realistic proportions, the modeling process started with the architectural plan of the building and the pictures taken of the real space.

Part of the furniture, including tables, chairs, goods disusers, and electronic devices consisted of downloaded assets integrated into the scene. The inserted components were carefully chosen to optimally blend in with the desired informal, functional, and clean atmosphere of the reproduced environment.

4.4 Player Controller and Input Management

The development of the user took advantage of primitives provided by the development environment to acquire the user's input, handle the user's movement, and create the interaction mechanisms with the barriers. As defined to create a usable educational simulation (see Section 4.2), the commands development followed the principle of simplicity, with the goal of creating a simulation with little cognitive overhead that would be suitable also for participants unfamiliar with VR. The user can use the joystick of the left controller to move in the environment and the grip and trigger buttons of either controller to interact with the barriers and the menu.

The choice of the locomotion system was a crucial decision that would greatly affect the experience of the user within the simulation. The goal was to make the experience as realistic as possible, trying to provide a high level of immersion (see Section 3.2.2). The issue with the available locomotion options is the possibility of causing motion sickness, therefore the balance between comfort and realism had to be trod carefully.

The different locomotion and turning options (Continuous Movement, Teleportation, Continuous Turning, and Snap Turning) were evaluated and compared by different members of the research group. The final decision was to adopt a Continuous Movement Locomotion System, moving forward in the direction where the user is looking. Said option was deemed the most intuitive and realistic with acceptable effects on motion sickness given the contained length of the simulation. The introduction of a teleportation system to move the user directly in front of each architectural barrier in case of discomfort was considered but then discarded in favour of a more realistic experience. The tuning of the user's speed, the choice of the highest quality rendering option, and the increased execution frame rate made it possible to reduce the sickness effects to a level deemed non-concerning.

Similarly to the locomotion system, the choice of the interaction mechanisms to adopt was crucial. The goal was to create simple and intuitive commands to avoid adding to the simulation cognitive overhead. The controls should also contribute to the user's positioning at an optimal distance from the architectural barriers. Different Interactor options (Ray Interactor, Poke Interactor, Grab Interactor, Direct Interactor, Gaze Interactor, Teleport Interactor) were provided by the XR Interaction Toolkit package and the Ray Interactor was chosen and installed on each controller.

The ray mechanism enabled users to interact with the architectural barriers from a distance, without requiring them to get too close to the target. To ensure participants would not interact from too far, a maximum radius of five meters was established for the Ray Interactor to remain operational. The rays' colour change was implemented to show users when they were pointing toward an interactable object, and users could get familiar with the mechanisms common to the whole simulation during the tutorial phase. Figure 4.8 shows the colour change mechanism of the controllers' raycast when hovering an interactable object during the tutorial. The chosen interaction mechanisms were assessed and approved by two researchers in the group and two informatics students to confirm their understandability and ease of use before introducing them in the simulation.

(a) **(b)** **(c)**

Figure 4.8: Demonstration of the raycast functioning mechanism. In (a) the raycast can be pointed towards objects in the environment to discover if they are interactable. In (b) interactable objects, like the cube in the tutorial, cause the raycast colour to change when hovered. In (c) all UI elements are interactable and trigger the raycast colour change.

4.5 User Interface

When entering the virtual environment, a canvas carrying a short explanation of the purpose and structure of the experience is presented to the users. The introduction allows participants to take some time before entering the main part of the simulation, adjust the headset positioning, ask questions to the supervisor in case of confusion before the beginning, and concentrate on the tasks and content of the experience. The introduction contains all the information participants are allowed to know before the experience and serves as a reminder of the simulation's goal. Figure 4.9 shows the content of the textual panel and demonstrates how the introduction is presented to the user.

After the initial introduction, the main menu shown in Figure 4.10 is presented to the user. The navigation menu shows which parts of the simulation can be accessed and instructs the user on which actions should be taken to go through the simulation. At the end of each simulation section, the user is required to go back to the menu, always reachable through a "menu" button as shown in Figure 4.8 on the right, and continue with a different scene or terminate the experience. The scenes are accessed in order, facing the tutorial first, the embellished scene second, and the sober scene with textual explanations last before quitting the experience (see Section 3.1).

Figure 4.9: The introduction to the experience is presented to the participants when they enter the simulation.

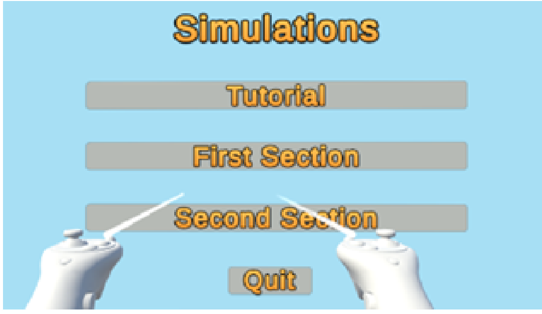


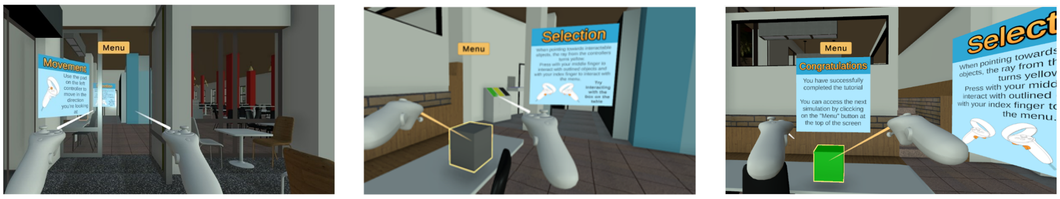
Figure 4.10: The navigation menu can be used to move between the simulation's different sections and quit.

4.6 Tutorial Implementation

The simulation tutorial has the goal of easing the user into the virtual environment. For the first time, the participants are exposed to the KIT cafeteria background, even if the architectural barriers are removed. As illustrated by the framework for educational simulations (see Section 2.3), an opportunity to familiarize with the environment has a positive impact on the simulation's ease of use. In the context of this prototype, the tutorial allows participants to satisfy one's curiosity by exploring the environment and getting acquainted with the commands. After reading an explanation, with an accompanying drawing on how to move, the user can take time to explore and feel comfortable with the setting.

Afterward, the user is directed toward a cube positioned in the scene and is instructed on how to interact with it, triggering a change of colour. The distinctive characteristics of interactable objects are already present, allowing the user to recognize the barriers in the following scenes as interactive objects. This is achieved by always using the same golden outline to delineate objects that the user should check, and the raycast colour change along with the haptic feedback on hovering (see Section 4.7.1) concur to help the user identify interactable objects. In the section of the simulation where the barriers have embellishments (see Section 4.7), other highlighting effects are added to increase the user's curiosity and draw their attention toward the barriers, but the outline is maintained across the whole simulation.

Examples of the provided indications and of the interaction mechanism that participants experiment with during the tutorial are shown in Figure 4.11.



(a) (b) (c)

Figure 4.11: Example of explanations during the tutorial phase of the simulation: the user is instructed on how to (a) move within the simulation, and (b) interact with objects. In (c) a colour change is triggered as a demonstration.

4.7 Embellished Scene

The first scene after the tutorial contains each one of the three barriers (see Section 3.4.5) in the embellished form. Each barrier in the embellished scene has multiple components as defined during the design phase of the embellishments (see Section 3.5.4):

- The highlighting mechanism that disappears when the user is in the barrier's proximity.
- The golden outline characteristic of all interactable objects within the simulation environment.
- The main object that represents a case of inaccessible design (e.g., the tall display device, the staircase without accessibility ramp, and the book with low-contrast writing).
- The animation that morphs the main object into an accessible version of itself (e.g., the shorter display device, the staircase with accompanying ramp, and the book with high-contrast writing).
- The set of particle effects triggered alongside the animation upon interaction with the user.
- The sound effects triggered by the user's interaction with the barriers.
- The haptic response activated when hovering or selecting the architectural barriers with the ray interactor.

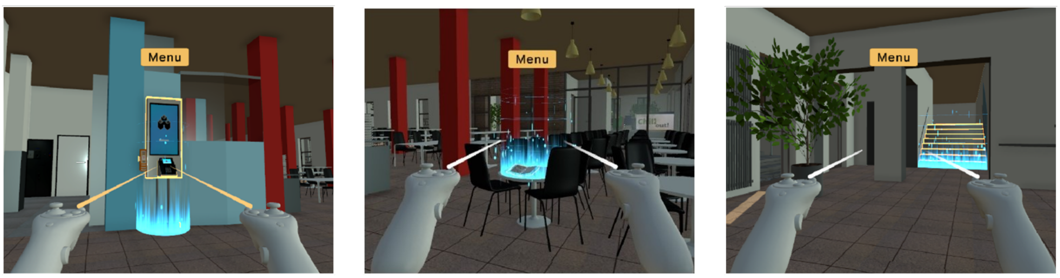
At the beginning of the scene, the architectural barriers are surrounded by the highlighting effect. When the user moves closer, the highlighting is deactivated revealing the concealed architectural barrier. Upon interaction with the outlined target, multiple events are triggered: haptic feedback is given through the controller, a combination of particle systems that depend on the specific barrier is activated, a sound effect is played, and an animation displaying the solution for the accessibility issue is displayed.

The interaction with the barriers is only possible when in their proximity. To interact the user needs to find them within the environment, move close enough to deactivate the highlighting, and point the raycast toward the outlined object. The barrier animation and effects are triggered by clicking the grip button of the controllers.

4.7.1 Highlighting Effect

To highlight the architectural barriers across the whole scene a consistent approach was used. The same effects were adapted to the shape of each barrier, to guide the user in the environment exploration and barrier recognition.

The object representing the barrier can be distinguished from the background by the presence of a golden outline (see Section 3.5.4). The outline is common to all the interactable objects across the whole simulation, making them recognizable also in the tutorial and the second scene. In the embellished scene though, an additional set of particle effects is used for highlighting. The integration of four particle systems is used to draw the user's attention toward the barriers and pique their curiosity during the environment exploration. The highlighting effect is composed of an animated blue ring of flames with rising dark and light sparks and a soft radial light illuminating the floor below the barrier. Examples of the highlighting for each architectural barrier are shown in Figure 4.12.



(a) **(b)** **(c)**

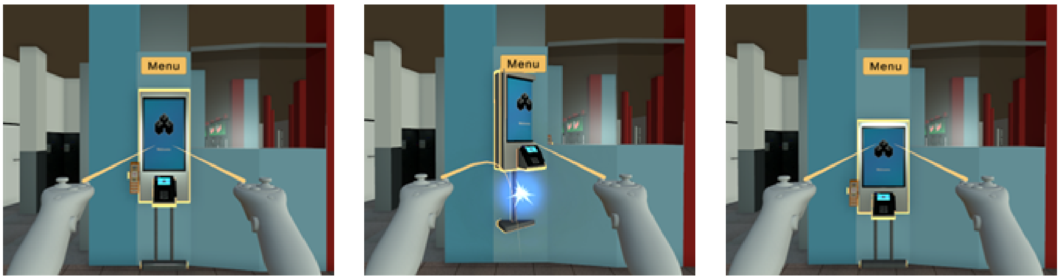
Figure 4.12: Embellishment in the form of compelling highlighting of the architectural barriers. The highlighting is applied in (a) to the too-tall display device, in (b) to the book with insufficient light to read, and in (c) to the inaccessible staircase.

The highlighting effect surrounding the architectural barriers is turned off when a closeness trigger is activated by the user's presence in the barrier's proximity. That allows the usage of very visible particle systems as highlighting without causing distractions from the other events activated upon interaction.

4.7.2 Animations

Each architectural barrier has a different animation, customised to display the solution to the accessibility issue as defined during the design phase (see Section 3.5.4).

The display device, shown in Figure 4.13, is an example of complex and fast animation that simulates a shrinking-size spell cast on the barrier. The small spatial change, uniform with the accessibility guidelines for the height of displays, consists of a contained height resize, bringing the display's height to 1.20m. An articulated animation with multiple components was created. The vertical shrinking and lowering transition of the object was combined with the completion of three fast turns to simulate a spell cast on the barrier that changes the final size of the object making its height accessible.

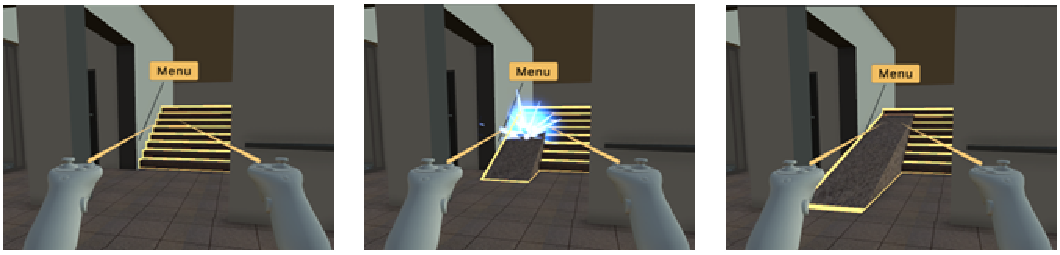


(a) **(b)** **(c)**

Figure 4.13: Example of the animation applied to the display device consisting of a jumping and turning effect while the object's height is reduced. In (a) the accessibility barrier is highlighted. In (b) the animation and contextual effects are activated. In (c) the accessible solution is displayed.

The ramp appearance for the staircase is an example of simple, slow and very visible animation. The remarkable spatial modification consists of a big accessibility ramp appearance. The transformation has low fidelity with the accessibility guidelines since a realistic ramp would that fits the space would be articulated and possibly difficult to understand. Preference was given to convey the overall message instead of focusing on the details.

For the staircase, shown in Figure 4.14, the animation is applied to an accessibility ramp. The slope appears from behind the steps and extends past it, sliding on the floor and covering a part of the stairs. The animation is slower and simpler with respect to the display one to assess the effect of speed and complexity on the user understanding.



(a) **(b)** **(c)**

Figure 4.14: Examples of the animation applied to the staircase, where an accessibility ramp is slowly drawn from behind the steps. In (a) the inaccessible staircase is highlighted. In (b) the ramp animation and contextual effects are activated. In (c) the accessible solution is displayed.

In the book's case, shown in Figure 4.15, to attract the user's attention to the scarce luminosity of the room, the book pages become brighter increasing the contrast with the writing. This animation consists of an immediate change.

(a) **(b)** **(c)**

Figure 4.15: Examples of the animation applied to the book, where the writing contrast changes to show the room light required for visually impaired individuals to optimally use their residual vision. In (a) the book with low contrast is highlighted. In (b) the book animation changes the contrast and contextual effects are activated. In (c) the accessible solution is displayed.

Each animation has a reversed counterpart that modifies the object back to its initial state. On the first interaction with the user, the solution to the barrier is shown, while, as a consequence of the second selection of the same barrier, the initial situation is restored. The users can trigger and undo the barrier modification repeatedly to be able to compare the options and reason for the displayed modifications.

4.7.3 Particle Effects

Each barrier has a set of particle systems that are activated as a response to the user's interaction along with the animation. The effects are all located in correspondence with the barrier's center at eye level and are accessories to the object animation.

In the case of the display and the staircase, four particle systems concur to create the final effect that reminds one of a small explosion. The effect, composed of an imploding glow, some lighting-like sparks, a flash of light, and a cloud of almost transparent smoke, is shown in Figure 4.14.b and Figure 4.13.b.

In the book's case, a single particle system accompanies the contrast increase. The effect, shown in Figure 4.15.b, was created to remind one of rising snow, with little glowing circles moving upwards from the ground to disappear before the ceiling.

4.7.4 Sound Effects

Along with the animation and the particle effects, a sound is triggered when the user interacts with the barriers. A neutral sound was chosen to involve the user's hearing sense in the experience without being distracting.

4.7.5 Haptic Effects

The personalization of the ray cast emitted by the controllers allows for changing the colour and integrating haptic feedback when hovering or selecting interactive objects. The effect is used, along with the highlighting, to help the user identify the interactable targets.

4.8 Textual Boards Scene

The second scene after the tutorial contains each of the three barriers (see Section 3.4.5) in the plain form. The goal is to have a sober counterpart to the first scene that uses text instead of animations and effects to explain the accessibility issues to the user. The user can reflect on the additional insight gained from the textual explanation and compare it with their understanding gained during the previous scene. With this separation of means of communication, it was possible to understand the contribution of each component, analysing them separately (see

Section 3.6.2). The content of each explanation is reported in Table 4.2 and Figure 4.16 shows how the textual explanations are displayed to the participants and their positioning with respect to the architectural barriers.

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Architectural Barrier	**Explanation Content**
Display Device Height Issue	This electronic device is used by students to upload money on the University Card, the payment method accepted within the premises. However, the elevated touch screen presents accessibility challenges for people in wheelchairs, as it is difficult for them to reach the screen's commands and effectively interact with them.
Book Low Luminosity Issue	This cafeteria exit lacks an accompanying accessibility ramp, making it inaccessible to people with mobility impairments and to wheelchair users. This is a crucial issue because this exit else serves as an emergency evacuation route and the absence of a ramp restricts the ability of certain individuals to use it during emergencies.
Staircase Missing Ramp Issue	The soft lighting in the cafeteria creates a relaxed atmosphere, ideal for informal student gatherings and collaborative study sessions. However, the low luminosity can be challenging for individuals with visual impairments, requiring them to bring additional equipment, like personal lamps, to be able to study effectively.

Table 4.2: Textual explanations of the accessibility issues presented in the simulation.

In this scene, the barriers carry the golden outline typical of the interactable objects of this prototype. Their location is already known to the user because it is shared with the previous scene and further highlighting was deemed not necessary.

When in the barrier's proximity, the user can interact by selecting it with the controllers. As a result, a textual board near the barrier is displayed and the user can read the explanation of the architectural issues and solutions.

The placement of the textual board was crucial because the goal was to position them in the user's field of view without hiding the barrier, which should still be available for checking. The final decision was to position the text either next to the barrier, as in the display and book's case, or above, like for the staircase.

(a) (b) (c)

Figure 4.16: Textual explanations of the architectural barriers. In (a) the excessive height of the display is explained. In (b) the insufficient light in the room is indicated as the issue. In (c) the problem of the missing accessibility ramp is detailed.

4.9 Optimization Methods and Other Expedients

The Universal Render Pipeline (URP) is one of the available rendering pipelines in Unity, alongside the High Definition Render Pipeline (HDRP) and the Built-In Render Pipeline. It was chosen for this project because of the advantages it offers like the ability to provide, across a wide variety of devices, high-quality graphics while maintaining optimized performance and high efficiency. The possibility of using dynamic lighting and to add post-processing effects were also positive features for the light management and the polishing of the project.

Another important aspect of the project's development was the optimization of the application to improve the user experience and reduce the chances of motion sickness due to delays or lags in the virtual world's response to the user's movements.

Draw calls are required every time an object is drawn on screen, often causing a calculation overhead that slows down the application, resulting in a reduced responsiveness of the simulation. Different optimization techniques were applied in this project to reduce the number of draw calls and consequently the computational overhead. An overview of the techniques is reported in Table 4.3.

The Occlusion Culling was carried out for walls and windows to avoid rendering furniture in rooms that cannot be seen from the user's position.

Static Batching was fundamental for this application because the reproduced virtual environment, including the building structure and the furniture, is stationary during the whole simulation. Only the user and the architectural barriers with annexed effects were excluded from this kind of optimization.

Different quality settings were compared and, given the different levels of motion sickness caused, the URP-High Fidelity was chosen because more enjoyable with respect to the other options.

Post-processing was introduced to finalize the look of the simulation, making

Optimization Technique	Description
Occlusion Culling	The technique is used to prevent the application from rendering objects that are not in the Camera view because covered by other elements in the scene.
Static Batching	The technique is used to improve the speed of the application when rendering stationary objects. By marking the objects as static, a unique Mesh is created, and the objects are rendered as one, speeding up the calculations of each frame.
Quality Settings	The customization allows balancing the trade-off between graphical quality and performance to best fit the project's needs.
Post Processing	The collection of techniques is used to polish the final look of the project after the initial rendering process. Multiple visual effects can be applied to improve the overall appearance of the scenes, including Tonemapping, White Balance, Bloom, and Anti-aliasing.

Table 4.3: Optimization techniques applied to improve light rendering and performance.

the atmosphere more welcoming by adding a slightly warm tint in the Bloom and increasing the temperature of the White Balance to twenty. The Tonemapping was set to Academy Color Encoding System (ACES) to adjust the brightness and contrast of the frames. Fast Approximate Anti-aliasing was used to fix the jagged appearance of the straight lines delimiting walls and furniture. The smoothing technique makes the lines slightly blurrier but improves the overall appearance of the virtual environment making it more realistic and immersive for the users.

Chapter 5

Evaluation Methodology

The objective of this thesis is to extract recurring patterns (see Section 5.2) and provide design recommendations (see Section 5.3) to build an educational VR simulation that sensitises about architectural barriers and accessible building design. Chapter 3 and 4 respectively discussed the prototype design and implementation while here is explained the method used to evaluate the simulation features (see Section 5.1). The prototype was tested by experts in the field of accessibility, building design and VR simulations and their feedback was collected during the interview process that followed the experience (see Section 5.1.3). The obtained insight was analysed using the TA method introduced by "Using thematic analysis in psychology" [29] (see Section 5.2). The themes obtained from the analysis (see Section 6.2.2) were used to define design recommendations for the development of VR simulations in similar contexts (see Section 6.3).

5.1 Prototype Evaluation

The features of the prototype were regularly tested within the research group during the development phase before involving experts to collect their feedback on the simulation.

The evaluation of the prototype was carried out by means of expert interviews. Five experts in the field of accessibility and building design experienced the VR simulation. After the completion semi-structured interviews followed to collect the participants' feedback. The chapter details the structure of the experiment (see Section 5.1.1, the process of setting up the simulation (see Section 5.1.2) and the testing phase with experts' interviews (see Section 5.1.3).

5.1.1 Structure of the Experiment

The experiment followed the same procedure for each one of the five participants; the tests were conducted over the course of three consecutive days.

Each test consisted of three subsequent phases, with short intervals in between for clarifications:

- Introduction to the purpose of the study with an explanation of the goal of the experiment.
- Experience of the VR simulation with supervision.
- Feedback collection with a semi-structured interview.

Introduction - The participants were instructed on the topic addressed by the study and the detailed procedure of the test. It was explained that they were supposed to find the same set of three architectural barriers in each one of the two scenes after following an introductory tutorial. They were instructed to focus on the feelings given by the simulation and on the impressions obtained from the interaction with the barriers because their feedback would be collected during an informal interview.

Simulation (see Section 5.1.2) - The participants experienced all three sections of the simulation following the prototype's instructions. Small suggestions were given if the participants requested clarifications.

Interview (see Section 5.1.3) - The semi-structured interviews followed the completion of the virtual experience to collect the experts feedback and opinions. The selection of the participants is detailed in Section 5.1.3, while Section 5.1.3 provides insight on the questions used as guideline. Notes were taken during the interviews (see Section 5.1.3) to be analysed for themes extraction (see Section 5.2).

5.1.2 Simulation Setup

This section explains the setup and procedure of the simulation that allows users to experience the virtual environment.

For this study, the Meta Quest 2 headset was connected to a laptop via a USB cable that enabled the communication between the two devices using the SideQuest platform. The choice allowed me to supervise the experiment and upload and start the simulation for the user. After an introductory explanation (see Section 5.1.1) the user joined the simulation by wearing the headset and started the experience after receiving the controllers. After entering the simulation, the user was guided through the different steps by the instructions available within the prototype. At the same time, we was able to follow every step by observing the streaming of the simulation on the laptop's screen. That allowed me to step in and support the participants with cues in case of confusion. we kept the suggestions to the minimum to avoid interfering with the test and influencing the user's experience.

The participants were given the option to either sit or stand during the simulation. For those unfamiliar with VR or prone to motion sickness, sitting was recommended for comfort and safety reasons. However, it was emphasized that this choice was not made to simulate being in a wheelchair, as this would contradict the study's objectives (see Section 1.2). Participants who were experienced with VR and confident they wouldn't experience motion sickness were advised to participate in the simulation while standing. The setting of the experiment, both in the sitting and standing option, is shown in picture Figure 5.1.

(a) **(b)**

Figure 5.1: Setup of the simulation for the experience with the experts. In (a) is presented the sitting option during the simulation. In (b) the standing option during is displayed instead.

5.1.3 Interview Conduction

To collect the experts feedback on the effectiveness and limitations of the prototype communication means, semi-structured interviews were conducted after the VR experience.

During the interviews, the questions were used as a guideline and to provide topics to discuss, but the participants were encouraged to talk about what they felt was most important. The eight questions ranged from general to specific, probing the participants' understanding and satisfaction with how the barriers were designed and explained. The two scenes containing the different barrier representations were analysed in detail, singularly and in comparison to each other. The appropriateness, informativeness, and understandability of the communication means were investigated, and the participants' overall impression was collected.

The session with each expert lasted indicatively an hour and we took detailed notes on the answers provided during the interviews.

Question Overview

The semi-structured interviews adhered to the following outline:

- What aspects of the simulation stood out to you? [Prompts: anything positive, anything negative

- What are your thoughts about the embellished barriers, meaning the animated barriers with the visual and sound effects? [Prompts: are they appropriate, are they informative]

- What are your thoughts about explaining the barriers with textual boards? [Prompt: are they appropriate, are they informative]

- Which way of representing the architectural barriers did you prefer and why?

- On the barriers' representation, is there anything you would add/remove/change?

- If you think about the barriers you just saw, what are the first things that come to your mind? [Prompt: Do you feel different about the two versions]

- Can you imagine using something like this in your everyday life? [Prompt: In what kind of applications/contexts]

- Do you have any additional feedback you'd like to share?

Selection of Participants

Expert participants were deliberately selected from within the campus community to assemble a diverse range of knowledge and backgrounds, fostering a combination of distinct yet complementary areas of expertise. This ensemble included specialists in assistive technologies with a specific emphasis on addressing visual impairments, as well as experts in the domains of inclusive and sustainable building design, and more broadly, the design of accessible and barrier-free environments (see Section 6.1).

The participants in the study covered a spectrum of familiarity levels with VR, ranging from individuals with no prior exposure to VR technology to those possessing significant experience (see Section 6.1). Furthermore, the choice of experts aimed to introduce diversity in terms of age, gender, and personality, facilitating the collection of heterogeneous feedback.

Feedback Transcription

Conducing expert interview with the university personnel does not require the KIT Ethics Committee to assess the questions asked. For privacy reasons recording the interviews was not allowed without explicit approval by the Ethics Committee and note taking was chosen as transcription method instead.

The feedback provided by the experts was collected during the interviews by means of note taking on paper. we tried to transcribe the spoken sentences with the highest accuracy possible to capture the intended meaning, tone and phrasing used by the experts.

The digital transcription of the notes was used as data source for the TA to identify the recurrent themes (see Section 5.2) and extract the design recommendations (see Section 5.3).

5.2 Thematic Analysis

TA is an interpretation method specifically designed to analyse data collected from subjective experiences within specific contexts. The TA technique by "Using thematic analysis in psychology" [29] was used to define patterns or themes within the data, organizing them into meaningful categories, and interpreting their underlying meaning.

Given the qualitative nature of the analysis, the methodology requires to explicitly state the frame and characteristics of the conduced TA to guarantee clarity and transparency of the results.

The TA of this study consists of a rich thematic description of the entire dataset and has the following characteristics:

- Inductive 'bottom up' approach because the analysis is data-driven on material collected specifically for this study.
- Semantic approach because the themes are identified at explicit level without looking for hidden meanings beyond what was transcribed. The analytic process then involves a progression from description of the data to interpretation of the patterns and their broader meaning.
- Essentialist/realist approach that relies on the assumption that the language reflects and enables us to articulate meaning and experience. The basis for the data understanding is sought in the individuals' psychologies and motivations instead of their socio-cultural contexts.

The analysis steps, as defined by "Using thematic analysis in psychology" [29] consist of reading and familiarisation (see Section 5.2.1), coding (see Section 5.2.2), and themes creation (see Section 5.2.3).

5.2.1 Reading and Familiarisation

For the first part of the TA process we had to familiarise myself with the data by transcribing it in digital format and actively reading the content multiple times.

During this phase we organised the notes dividing them by question and sorting them by experts to facilitate the process of patterns recognition. To actively read the material we used colours to identify visibly recurring categories and bookmarks to pair each data section with short schematic descriptions. Similar words were used for sentences that addressed the same matter, with the goal of identifying recurring elements.

After achieving a satisfactory familiarity level and understanding of the raw data, we proceeded with the coding phase (see Section 5.2.2).

5.2.2 Coding

The coding phase consists of systematically noting the data interesting features to identify aspects that may form the basis of repeated patterns; organising the data into meaningful groups is the goal of this step.

In this stage of the analysis, we used the 'complete coding' technique, pairing each data segment extracted from the interviews' transcription with a description of all its interesting features. Instead of using repeated sentences for coding, we introduced grouping suggestions already at this stage and maintained a description of the interesting aspects because it was more spontaneous. It is not required by the methodology, but it helped me better visualise and understand the data with without losing context. The codes' categories and sub-categories don't match the themes that resulted from the analysis (see Section 6.2), but they were a starting point to see patterns and correlations among the data items.

we used a spreadsheet to collect all the pairings and their identifying information. Each created data item contained:

- the data extract quoted from the interviews' transcription
- a short description of the coded interesting feature
- a category and, when possible, a sub-category to facilitate grouping and sorting.
- the question number and the expert identifier to permit backtracking and maintain context.

Each data extract birthed one or more codes, to identify as many potential patterns as possible. 272 codes were generated from 139 data extracts, and 11 groups and 26 sub-groups were identified during this phase.

5.2.3 Creating Themes

The process of creating cohesive and distinctive themes from the codes generated in the previous phase (see Section 5.2.2) is iterative and very time consuming. Nevertheless, the effort and diligence required during this step are fundamental to produce a functioning thematic map (see Section 6.2.1) and a coherent set of themes (see Section 6.2.2).

A theme is a unit that "captures something important about the data in relation to the research question and represents some level of patterned response or meaning within the data set" [29]. A set of themes is the result of combining the codes extracted in the previous phase (see Section 5.2.2) in groups that maintain the impression of the initial dataset while organizing the concepts coherently.

During this phase we looked for patterns across the codes' categories and tried different possible grouping strategies to find over-arching themes and sub-themes. After multiple iterations we reached a satisfying thematic map and proceeded to polish the themes. To refine the themes, we followed the concept of internal homogeneity and external heterogeneity [29]. To satisfy the Internal homogeneity criteria the data items belonging to each theme and sub-theme were checked for inconsistencies, moving the single items where they best fit. To satisfy the external heterogeneity requirement we traced back to the data extracts to assess where some of the less intuitive items belonged, looking for the original meaning with the new themes in mind.

As a final step, the items belonging to the same final category and coming from the same expert were collapsed to reduce redundant information. The category 'miscellaneous' was emptied to assign all data extracts to a theme in the final classification. The final version of the thematic map (see Section 6.2.1) was produced.

At the conclusion of this process, each data item was categorised to a theme, a sub-theme, and, when applicable, a division. This resulted in the identification of 6 main categories, with 20 themes and 17 sub-themes. The final version of the themes is discussed in Section 6.2.2 and the detailed descriptions are reported in the appendix (see Appendix B).

5.3 Extracting Design Recommendations

At the end of the theme's extraction (see Section 5.2.3) by means of the TA, the research questions (see Section 1.3) could be answered on a theoretical level (see Section 7.1). Design recommendations (see Section 6.3) were extracted from the themes integrating them with insights from the literature (see Chapter 2) to produce directly applicable suggestions for developers working on similar projects in the future (see Section 8.4). Table 6.1 shows how the different themes contributed to each recommendation.

Chapter 6

Findings

6.1 Description of Participants

To test the prototype features we conducted 5 semi-structured expert interviews (see Section 5.1). The experts participating to the evaluation are identified as E1 to E5 for anonymity.

The experts were chosen for their background and field of expertise in accessibility and building design to receive insightful feedback. Their diversity in gender, age, personality, and familiarity with VR simulations was a desired feature to obtain a comprehensive range of perspectives and ensure well-rounded evaluations.

E1 is architecture professor at KIT and specializes in sustainable building design with attention to universal design among other factors. They lead a research group dedicated to accessibility, where they develop and evaluate technologies and spatial configurations to empower disabled individuals and promote equitable participation in society. This expert had limited previous experiences with VR simulations.

E2 has a managerial role in a research group at KIT that focuses on digital accessibility and assistive technologies. Their research supports visually impaired students during their studies while focusing on developing innovative assistive technologies to empower individuals with disabilities, particularly those who are visually impaired. This expert was unfamiliar with VR and additionally struggled with the experience because they could not wear glasses beneath the headset.

E3 and E5 are part of the staff of the same research group as E2 and focus on assistive technologies for visually impaired individuals. Both experts have extensive previous experience with VR. In fact, E3 possess a device at home and E5 habitually uses this technology for research. E3 is very proficient during the experience, completing every step autonomously. Similarly, E5 is very independent during the simulation and takes their time exploring the virtual environment almost entirely.

E4 has a background in architecture with specialization in publicly accessible buildings, both new and historical. Their current research focuses on how buildings and cities could be designed to support equitable access and independence of all people. This expert was unfamiliar with VR and was slightly hesitant during the experience; nevertheless, they went through the simulation carefully, paying attention to every detail, and ensuring thorough comprehension before advancing.

The background, psychology, and experience of the participants is fundamental to understand and interpret their statements regarding the simulation prototype reported in the appendix along with the detailed discussion of the themes (see Appendix B).

6.2 Thematic Analysis Results

This section presents the results of the TA conducted during this study (see Section 5.2) to analyse the experts feedback on the prototypes features. The themes obtained with the analysis process are explained in Section 6.2.2 and the thematic map displaying the correlation between the categories is shown in Section 6.2.1. The detailed themes backed up with citations of the experts' feedback can be found in the appendix (see Appendix B).

6.2.1 Thematic Map

Figure 6.1 shows the final version of the thematic map containing the correlation among the themes extracted from the experts' feedback.

6.2.2 Themes

The themes were extracted from the interviews' notes (see Section 5.1.3) following the TA methodology by "Using thematic analysis in psychology" [29] (see Section 5.2). They represent the main achievement of this study because they are the elaboration of the feedback on the prototype's features and contain the information needed to answer to the research questions (see Section 1.3).

The themes extracted from the experts' feedback are divided into six categories that represent the successive steps of the interaction with the elements of the simulation and the effects of the overall experience. The themes are grouped in curiosity (see Section 6.2.2), attention (see Section 6.2.2), comprehension (see Section 6.2.2), reflection (see Section 6.2.2), completeness (see Section 6.2.2), and employment (see Section 6.2.2). The complete and detailed description of all the themes with extracts from the experts' feedback can be found in the appendix (see Appendix B) and the drawn design recommendations can be found in Section 6.3.

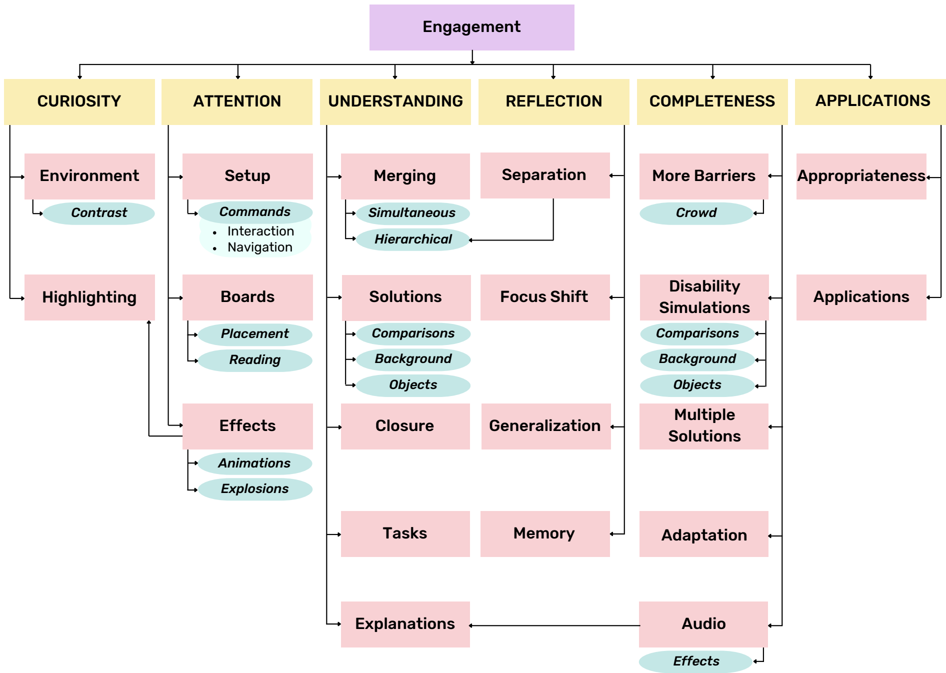

Figure 6.1: Thematic map displaying the correlation of themes identified in the experts' feedback by means of TA

Curiosity

The category 'Curiosity' (see T-1) analyses how the simulation's components influence the user's ability to immerse themselves in the simulation, identify the key targets of the experience, and be drawn toward the interactable objects. The two main contributors to the users' curiosity toward the simulation's targets are the virtual environment and the highlighting effects.

The environment (see T-1.1) serves as the initial catalyst for the user's curiosity, enhancing immersion and intriguing the users. By juxtaposing a realistic background with captivating effects (see T-1.1.1), the user's attention is piqued and guided towards the architectural barriers, focal point of the experience.

The chosen highlighting mechanism (see T-1.2), consisting of a blue sparkling flame (see Section 4.7.1) around the interactable objects, successfully captivate the users without overshadowing the simulation's core objectives, fostering curiosity and engagement.

Attention

The category ‘Attention’ (see T-2) explores how different factors influence the user’s ability to stay focused on the relevant elements of the simulation and identifies potential distractions.

The information panels (see T-2.1) are placed next to the architectural barrier in the scene free of embellishments and animations. The boards placement (see T-2.1.1) next to the architectural barriers had a detrimental effect on the users focus because it caused readability issues and diverted the users attention from the barriers. The need to read (see T-2.1.2) in VR also negatively affected the users focus on the architectural barriers because of the struggle necessary to read the textual explanations.

The visual effects (see T-2.2) added visual appeal to the simulation, but concerns were raised about their dominance. The explosion effect (see T-2.2.1) was deemed very distracting, often overshadowing the animation happening at the same time. In the animations case (see T-2.2.2) the imprecisions in the displayed solutions were identified as a possible distraction for architects and architecture students that habitually focus on small design details.

The simulation setup (see T-2.3) can also be source of distractions, affecting the user’s immersion and ability to focus. The simplicity of the commands (see T-2.3.1), both for navigation (see T-2.3.1.2) and interaction (see T-2.3.1.1), was crucial to minimize distractions due to unfamiliarity with the simulation.

Comprehension

The category ‘Comprehension’ (see T-3) investigates the understandability of the architectural barriers issues and solutions represented during the simulation and the efficacy of the delivery means.

The visualised solutions (see T-3.1) effectively demonstrate accessible design options, successfully aiding comprehension. Visualizing the modifications enhances the user’s understanding of accessibility challenges and potential alterations. Direct comparisons (see T-3.1.1) between pre- and post-modification states are fundamental to support understanding, especially in case of small changes that can be difficult to detect. Prior knowledge (see T-3.1.2) also impacts the participant’s comprehension of the displayed architectural barriers. Unfamiliarity with accessibility issues, especially visual impairments, may hinder comprehension and including more examples and explanations would be beneficial, particularly for less recognized disabilities. The careful selection of objects (see T-3.1.3) that represent the architectural barriers is crucial to accurately convey the accessibility issues. Inappropriate objects choices may distort or trivialize the represented concepts resulting in an inaccurate understanding.

The textual explanations (see T-3.2) are fundamental to complement the understanding gained from the visual representations. The level of detail should be tailored to the target audience, balancing informativeness and text length to avoid overwhelming the participants.

The combining visual and textual explanations (see T-3.3) is uniformly believed to enhances understanding. The simultaneous merging option (see T-3.3.1) involves overlaying the interactable architectural barriers with brief textual explanations of key features, reinforcing comprehension through immediate support. conversely, the hierarchical merging approach (see T-3.3.2) consists of delaying the textual explanation with respect to the visualisation of the accessibility solution. This alternative provides flexibility in learning pace and fosters independent reasoning before clarification.

A feedback mechanism such as colour changes could be introduced to improve clarity on tasks termination (see T-3.4). Providing clear goals and directions (see T-3.5) also improves engagement and understanding. Incorporating procedural tasks and clearly defining the experience's objectives can guide users and reinforce learning outcomes.

Reflection

The category 'Reflection' (see T-4) discusses the factors that contribute to and stimulate the users' pondering process on the experience's displayed architectural barriers and conveyed information.

The first component that, according to the experts, stimulates autonomous thinking is the temporal separation (see T-4.1) between the animated solutions and the textual explanations. Players formulate hypotheses before receiving clarifications, fostering a more engaged learning experience, and allowing for independent understanding and successive reflection.

An important component of the reflective process is the generalisation capability (see T-4.2). The textual explanations successfully foster abstract conceptualization and recognition of similar issues, enhancing long-term reflection. Conversely, visual examples of architectural barriers only aid anecdotal understanding, without contributing to the generalisation process.

Remembering concepts (see T-4.3) from the simulation is a fundamental component of the reflection process. VR simulations enhance memory retention compared to traditional educational materials by providing interactive learning environments. However, prolonged experiences can negatively affect recall. Hence, concise summaries and reminders of crucial information are essential to facilitate retention and prevent cognitive overload for the users. The result of the reflective process sparked by the educational experience is the possibility of a focus shift (see T-4.4) in the interpretation of the architectural barriers concept. Displaying bad design choices and possible solutions shifts the thinking process from the issues caused by the architectural barriers to the architectural barriers as issue. In fact, highlighting solutions fosters a proactive mindset, encouraging critical thinking and reflection on previously unnoticed issues.

Completeness

The category ‘Completeness’ (see T-5) analyses suggestions emerged during the interviews on how to improve the simulation’s fulfilment. Advantages and disadvantages of imagined mechanisms and expansions are discussed here, highlighting possible enhancements and concerns. However, it’s important to note that the discussed features were not experienced by the participants because not part of the prototype.

The presence of auditory features (see T-5.1) was dearly missed by the majority of the participants. While the study focused primarily on visual information (see Section 3.5.4), feedback indicates a need for increased auditory cues and explanations. The experts proposed incorporating audio options for textual explanations (see T-5.1.1) to improve accessibility and immersion in the simulation. Additionally, auditory effects (see T-5.1.2) could add to the embellishments (see Section 3.2.2.5) and facilitate understanding.

The introduction of disability simulation features (see T-5.2) was perceived by the experts as an area of possible enhancement of the simulation’s educative potential. It was highlighted that the option to sit during the simulation (see T-5.2.3) was perceived as counterproductive to the study’s goals of not simulating disabilities, as it inevitably reminded the participants of being in a wheelchair. Perspective taking (see T-5.2.1) by adopting the viewpoints of visually impaired or wheelchair users was suggested to directly experience the challenges caused by architectural barriers. Simulating distress (see T-5.2.2) caused by the design choices was also recommended as a tool to foster empathy and amplify reflection. Both options would defeat the goal of this study (see Section 2.1.3) and the presence of this form of feedback suggests how disability simulations are still perceived to be valuable tools to nurture compassion and awareness (see Section 2.1).

The possibility of increasing the number of displayed barriers (see T-5.3) during the simulation was proposed to provide more comprehensive information on the accessible design topic. Introducing additional disabilities and architectural barriers could enhance the completeness of the experience, though careful consideration of length and complexity is necessary to avoid overwhelming participants. While not included in the prototype (see Section 3.2.1), introducing crowds (see T-5.3.1) as architectural barriers was suggested to enhance realism and awareness of obstacles created by high people density.

The participants also indicated that increasing the simulation’s flexibility to adapt to user preferences (see T-5.4) would be an advancement for the prototype. Recommendations included personalizing settings during the introduction and adapting textual explanations based on the user's position. While adaptable features could improve the user experience, simplicity and focus on architectural barriers should remain priorities to prevent overwhelming participants.

Employment

The category 'Employment' (see T-6) analyses potential expansions of the prototype as an educational and awareness tool to sensitise and instruct about architectural barriers and buildings' accessibility.

Experts appreciated the prototype's concept, particularly its focus on solutions and the simplicity of its commands. The simulation's principles were deemed appropriate (see T-6.1) for a tool to raise awareness and educate about public spaces accessibility.

Various applications (see T-6.1) of the prototype's principles were discussed, including raising awareness among the general population, educating architecture and building design students, and training personnel working with disabled individuals.

6.3 Design Recommendations

This section collects all the design recommendations (see Section 5.3) extracted from the themes (see Section 6.2). The themes extraction process (see Section 5.2) categorised all the insight obtained from the expert dividing according to recurrent topics and patterns. Nevertheless, combining insight from multiple themes and introducing suggestion provided directly from the experts allowed producing comprehensive and more detailed indications. Table 6.1 shows how the different themes contributed to each recommendation.

Recommendations	**Themes**
DR-1: Curiosity	T1: Curiosity
DR-1.1: Environment	T1.1: Environment
DR-1.2: Contrast	T1.1.1: Contrast
DR-1.3: Highlighting	T1.2: Highlighting
DR-2: Attention	T2: Attention T5: Completeness T6: Employment
DR-2.1: Boards	T2.1: Boards
DR-2.1.1: Boards Placement	T2.1.1: Placement
DR-2.1.2: Text Readability	T2.1.2: Reading
DR-2.1.3: Auditory Explanations	T5.1.1: Audio Explanations

DR-2.2: Effects	T2.2: Effects
DR-2.2.1 – Hierarchy DR-2.2.2 – Visibility DR-2.2.3 – Frequency	T2.2.2: Explosions T2.2.1: Animations
DR-2.2.4 – Appropriateness	T6.1: Appropriateness
DR-2.2.5 – Completeness	T5.1.2: Audio Effects T3.4: Closure
DR-2.3: Setup	T2.3: Setup
DR-2.3.1: Comfort	T5.1: Audio T5.4: Adaptation T5.2.3: Sitting Position
DR-2.3.2: Structure	T3.5: Tasks
DR-2.3.3: Commands	T2.3.1: Commands T2.3.1.1: Interaction T2.3.1.2: Navigation
DR-3: Comprehension	T3: Comprehension T4: Reflection T5: Completeness T6: Employment
DR-3.1: Solutions	T3.1: Solutions
DR-3.1.1: Precision	T2.2.1: Animations T3.1.3 Objects T6.2: Applications
DR-3.1.2: Representativeness	T5.3: More Barriers
DR-3.1.3: Understandability	T3.1.1: Comparisons
DR-3.1.4: Informativeness	T3.1.2: Background Information
DR-3.2: Textual Explanations	T3.2: Explanations
DR-3.2.1: Completeness DR-3.2.2: Appropriateness DR-3.2.3: Brevity	T6.1: Appropriateness T6.2: Applications
DR-3.3: Merged communication means	T3.3: Merging
DR-3.3.1: Simultaneous Merging	T3.3.1: Simultaneous Merging
DR-3.3.2: Delayed explanation	T3.3.2: Hierarchical Merging T4.1: Separation
DR-3.3.3: Increased interactivity	T5.3: More Barriers
DR-4: Reflection	T4: Reflection T5: Completeness
DR-4.1: Memory DR-4.1.1: Information Density	T4.3: Memory

DR-4.1.2: Overview	
DR-4.2: Generalisation	T4.2: Generalisation
DR-4.2.1: Free exploration	T1.1: Environment
DR-4.2.2: Multiple Issues DR-4.2.3: Multiple Solutions	T5.3: More Barriers T5.3.1: Crowd

Table 6.1: Mapping between design recommendations (DR) and themes (T) that contributed to them.

6.3.1 Curiosity

DR-1: Curiosity – This section discusses suggestions to improve the user's ability distinguish the targets they're supposed to direct their attention to and the background of the simulation. Capturing the user's attention and sparking their curiosity for the desired items is the first step toward meaningful interactions and satisfactory comprehension during the VR experience.

DR-1.1: Environment – The virtual environment specific choice is not very relevant, but the reproduction process should value realism while refraining from inserting too many details. The features of the background should not interfere with the user's focus on the simulation targets while providing relatable and familiar surroundings.

DR-1.2: Contrast – Contrasting aesthetics can be used to pique the user's curiosity and aid them in identifying interactable objects within the environment. As suggested by Expert3, the contrast can be more or less extreme depending on the number of targets and the desired simplicity in identifying them.

> E3: You could dim everything but the barriers when showing all the problems in the cafeteria that are so many.

DR-1.3: Highlighting – Permanent and deactivatable effects can be used to aid the user in recognising the interactable objects of the simulation. The highlighting should not interfere with the user's attention on the target object while the user is interacting with it. Therefore, the highlighting can either be: permanent and subtle, or visually striking and turned off during the interaction.

6.3.2 Attention

DR-2: This section explores suggestions to improve the user's ability to concentrate on the parts of the simulation that are relevant to their education. The limitation of distractions is fundamental to create the best conditions for clear comprehension of what is shown.

DR-2.1: Boards – Panels can be used to carry information relevant to the experience if their positioning (see DR-2.1.1) and readability (see DR-2.1.2) are comfortable for the user. Additionally, an alternative way of receiving the same information, like auditory explanations (see DR-2.1.3).

> DR-2.1.1: Boards Placement – The panels should be positioned in the user's field of view to be easily noticed. Additionally, they should not hide the target they contain information about. As suggested by Expert3, possible solutions are making the board's position adaptive to the user or having smaller portions of text directly on the target's features they discuss.
>
> > E3: You could make board positioning adaptive to the user position, like for the menu button. You could use relative distance and positioning and you can allow to hide the boards.
> >
> > E3: Notes could be taken specifically on the barrier to show what exactly the text refers to.
>
> DR-2.1.2: Text Readability – To ensure the best possible readability in VR, text length and formatting should be carefully considered. The text length for each panel should be contained to avoid overwhelming the user. Expert5 suggested introducing keywords highlighting to speed up the reading process and Expert1 specifies that text justification and all-uppercase words should be avoided to improve readability.
>
> > E5: Introducing highlighting in the text would allow to go through it faster, but additional info is very important.
> >
> > E1: The readability of the panels would be better if the text was aligned to the right instead of justified. [. . .] The all-uppercase writing of the boards header makes it more difficult to distinguish the letters.
>
> DR-2.1.3: Auditory Explanations – Both Expert2 and Expert5 suggest that an alternative to written explanations would be having a read out loud option. The possibility would facilitate understanding and allow participants to remain focused on the architectural barriers displayed while being informed about limitations.
>
> > E2: I think the second part is appropriate and understandable, but a different way of explaining, like audio, could improve the experience. In fact, reading without my glasses was difficult. Observing the animation while listening to the audio would be better.
> >
> > E5: You could incorporate some audio feedback. Text is hard to read in VR, you could choose to have it read out loud with a button.

DR-2.2: Effects – Effects can be used to improve the simulation aesthetic, reinforce concepts, and carry information relevant to the experience. The hierarchy of the effects (see DR-2.2.1) should be carefully defined to prevent distracting the user from the core events they're supposed to pay attention to. The visibility of embellishments (see DR-2.2.2) should be balanced with their frequency (see DR-2.2.3), and the chosen effects should be suitable (see DR-2.2.4) for the application's target audience. Additionally, multiple sensory channels should be addressed, including auditory and haptic feedback (see DR-2.2.5).

> DR-2.2.1 – Hierarchy: Effects conveying information relevant to the experience, like the animations, should be very visible with respect to secondary effects that serve as reinforcement. Reversing the hierarchy might create confusion because most of the user's attention would be on the wrong event as highlighted by Expert4.
>
> > E4: The effects activated when clicking, the lighting explosion is confusing, it caught a lot of my attention on the sparkles other than the object and its animation. In fact, it took me a few attempts to actually get what was happening. I think the sparkles are distracting.
>
> DR-2.2.2 – Visibility: Concentrated effects with bright colours are very visible and should be used for effects carrying information fundamental to understanding. As suggested by Expert1, secondary effects, that reinforce information provided with other means, should be more subtle and distributed to avoid capturing all the user's attention.
>
> > E1: More subtle embellishments would allow to focus on the solution, meaning the animation.
>
> DR-2.2.3 – Frequency: From Expert1's feedback can be drawn that, in case of frequently recurring effects, more nuanced and dispersed embellishments should be preferred to avoid overwhelming or fatiguing the user. Conversely, for effects that are rarely triggered, slightly bolder embellishments can be chosen.
>
> > E1: In case of more barriers, it would be better to remove some highlighting, there's too much glitter.
>
> DR-2.2.4 – Appropriateness: Expert4 highlights that the visibility of the effects and the chosen aesthetic should fit the application's target audience. Exaggerated and very colourful effects should be avoided when developing business-related simulations. On the other hand, the embellishments contribute to piquing and directing the user's curiosity, and more captivating and mesmerizing effects should be considered for informal settings.

E4: The appropriateness depends on the target group. The effects are fine to get a lot of attention, for the general population, but for more of a serious/business context, something different and less playful should be used, like a spotlight effect.

DR-2.2.5 – Completeness: According to the dual coding theory (see Section 2.3) and as suggested by Expert3, multisensory feedback should be provided to improve comprehension and immersion during the experience. Auditory and haptic effects should be introduced to favour clarity and reinforce concepts connected to the interaction.

E3: Audio feedback should be included for multisensory feedback, other than the explanation with a loud reader, and the tactile feedback. [. . .] The display animation is difficult to spot, some audio could be used to suggest that the display is shrinking and going down. The animation could be only lowering and shrinking, with no jump.

DR-2.3: Setup – The simulation setup should not interfere with the experience to avoid distracting the user and compromising their immersion. Measures should be taken to guarantee comfort (see DR-2.3.1) during the experience and clarity of the simulation's structure (see DR-2.3.2) and commands (see DR-2.3.3).

DR-2.3.1: Comfort – Comfort during the experience favours immersion and concentration on the simulation's content. A lightweight headset should be considered to favour accessibility and inclusion of all participants, while auditory cues and explanations (see DR-2.1.3) should be integrated within the simulation to assist visually impaired users. Additionally, as highlighted by Expert1, the sitting position during VR experiences on accessibility and architectural barriers inevitably reminds users of being in a wheelchair. If the simulation is not intended to replicate motion impairment, sitting during the experience should be avoided.

E1: On the concept and the barriers explanation, sitting makes feel like disabled which is not intentional. Sitting means being on a wheelchair.

DR-2.3.2: Structure – The participants' attention should be directed to the educative insight presented within the virtual experience. To avoid additionally contributing to the user's cognitive load, the structure of the simulation should be straightforward and clear. Always accessible reminders of the simulation's goal and a series of tasks to complete could be used to guide the user during the experience. Direct advice from the experts is reported below.

E3: You could have user cases to have the user going through a procedure task. As an improvement having a task would be better. You do the task, and the barriers appear while you do it. It would work to get people into place with a task and then activate the barriers on the way.

E4: It's less important, but I would specify that there are three items to find. It's good to know as a participant that there's another one. Having more directions on what to do would be an improvement.

E5: Also, telling the goal of the experience and giving more info on the desired outcome would be better. Not knowing during the simulation makes understanding harder. Knowing the goal helps understanding what to look for.

DR-2.3.3: Commands – The complexity of commands and the difficulty to interact in the VR simulation affect the users' attention and cognitive load as explained by Expert4. Straightforward commands and simple navigation and interaction mechanisms should be preferred. Using a single controller and minimizing the number of different mechanics should be considered to create a straightforward system as suggested by Expert2. A tutorial and familiarisation phase should be included in the simulation process for the user to get acquainted with the commands before entering the main section of the experience. Particular attention to this recommendation should be paid if the participants are likely to be unfamiliar with VR.

E2: Also, there's no need for both controllers since they have the same functionality.

E4: The moving is on the left only, while on the right would be more intuitive. VR has an impact on new people. Getting confident with VR controls takes some of the focus. The tutorial was good and useful indeed.

E4: It's tricky to catch the items like the menu button and the book. Bigger clickable containers could be used because a lot of focus goes into hitting the book right. [. . .] I would add a bigger padding to hit the menu button or the book, a bigger clickable area.

6.3.3 Comprehension

DR-3: This section explores suggestions to improve the user's comprehension of the insight and information provided during the simulation.

DR-3.1: Solutions – In the context of an educational tool to sensitize about architectural barriers and solutions, particular attention needs to be paid to precision (see DR-3.1.1), representativeness (see DR-3.1.2), understandability (see DR-3.1.3), and informativeness (see DR-3.1.4) of the proposed environment modifications.

DR-3.1.1: Precision – The accuracy in the solution representation is crucial to convey correct information during the simulation. In educational simulations aimed at individuals studying and working on inclusive design and accessibility measures, the displayed solutions must adhere closely to all accessibility standards as highlighted by Expert1. Conversely, for applications aimed at raising awareness about architectural barriers among the general population, conveying the general idea is paramount. The displayed solutions should correctly represent the main features without unnecessary details to guarantee the clarity of the concept.

> E1: I'm disturbed by the solution coming up, in fact the solution should be more precise like the ramp that has better readability. A solution must be a solution but also it makes think about the difficulty to fit a solution in an existing environment. [. . .] More detailed solutions would be better for architecture students; for the general population less strict is fine. For example, the ramp reaches the second step and must be 6% at most. Details matter for architects.

Additionally, the objects chosen to represent the architectural barriers need to be accurately evaluated to avoid reinforcing stereotypes or trivialising issues. As highlighted by Expert5, the book chosen to highlight the scarce luminosity of the environment, trivialised the problem. Participants were led to believe that using a tablet instead of reading on books would suffice to solve the problem. A different item, like food for lunch on the cafeteria tray, would have shown how people with visual impairment would be unable to recognise what they purchased in the scarce light conditions, showing how the dimly lit room can be an architectural barrier.

> E5: Showing the book as solution, people would think that the solution is to just use something with retro illumination. With the book to representation of the barrier, people might not get the size and all the sides of the problem.

DR-3.1.2: Representativeness – Various solutions can be implemented to address an accessibility issue, and that feature could be integrated into the simulation to facilitate comparison of options. Presenting multiple variations of the solution to the user for comparison can enhance comprehension and foster a deeper understanding of the barriers and potential solutions depicted. Suggestions from Expert3 are reported below.

> E3: It is nice, but more info and examples could be interesting, or more solutions for each barrier could be displayed. For example, a sliding display for the first barrier, some light settings for the book, and multiple

> ramp configurations could be presented as solutions. You could choose which ramp to show when clicking to allow comparing solutions. In the future, you could provide ramps and ask the user to place the solution themselves.

DR-3.1.3: Understandability – To ensure the changes are easily identifiable and the solutions are understandable, a clear reference system should be provided to the user as highlighted by Expert2. Introducing static objects with well-known features, such as a defined height or size, helps the user detect subtle changes in the architectural barriers that might otherwise be overlooked, thus preventing confusion.

> E2: On the first and second barrier, the difference is not noticeable enough. [...] You have no comparison with a person to see the problem. Not everyone knows or recognizes the problem, previous knowledge is needed.

DR-3.1.4: Informativeness – The displayed solutions must be clear and understandable. When selecting and designing architectural barriers, consideration should be given to the participants' background knowledge. Additionally, it is important to investigate the users' familiarity with the targeted disabilities, as Expert5 highlights that some may be more widely recognized than others.

> E5: In combination with the first part, it can be considered informative, to get specific info. Otherwise, more background knowledge would be required. For example, with the book I'm not sure if people with no background would get it without the explanation. It is harder to understand when visual impairment is the target group. People cannot get a picture of the disability in their head; the individuality of the problems is not common knowledge, and more info is needed.

DR-3.2: Textual Explanations – In the context of an educational tool to sensitize about architectural barriers and solutions, textual explanations complement the user's understanding of the displayed concepts. Thanks to the written insight, additional information can be conveyed (see DR-3.2.1). Nevertheless, the content's level of detail should be tailored to the application's target audience (see DR-3.2.2) while keeping the text length contained (see DR-3.2.3), ensuring elevated readability (see DR-2.1), and providing alternative means (see DR-3.3).

DR-3.2.1: Completeness – Additional insight should be provided in textual format if no other means are suitable. An example from this study highlighted by Expert5 on the additional information provided on the staircase as an emergency exit. The textual explanation is used to highlight how the absence of the accessibility ramp would prevent individuals with motion impairments from leaving the building through the closest exit in case of emergency. This information could not be represented contextually to the animation and was presented to the user in written form as additional information. Details should be added and referred to the user to provide an exhaustive educational experience.

> E5: The explanation is useful to be able afterwards to specifically state the problem. For example, the emergency exit you don't get from the animation.

DR-3.2.2: Appropriateness – The amount of detail contained in the explanations needs to be tailored to the application's target audience and their background knowledge. Sensitizing the general population or creating a tool to educate about accessible design guidelines would require different levels of detail in the information boards.

DR-3.2.3: Brevity – The textual explanations only complement understanding gained through other communicative methods during the simulation. It's essential that the content stays straightforward and concise, to avoid overwhelming and tiring the participants with excessive lengths of text to read. Brevity of explanations is fundamental due to the low readability (see DR-2.1.2) in VR. To create dynamic and captivating experiences, most of the information should be conveyed with alternative means like animations (see DR-3.1). Therefore, text should be only used to reinforce the most relevant points and provide additional insight when strictly necessary.

DR-3.3: Merged communication means – Merging different communication means has a positive impact on comprehension, retention, and elaboration of concepts (see Section 2.3). Textual feedback can be paired with other visual communication means (see DR-3.3.1) but delaying the explanation can be used to foster autonomous thinking (see DR-3.3.2). Increased interactivity (see DR-3.3.3) could also be used to promote reasoning on the displayed issues and possible solutions.

DR-3.3.1: Simultaneous Merging – Providing different communication means simultaneously enhances the chances of comprehensive and solid understanding of the represented topics. In the context of an educational tool to sensitize about architectural barriers and solutions, the animations (see DR-3.1) and the textual explanations (see DR-3.2) can be superimposed to convey basic information and additional details simultaneously. Additionally, embellishments, consisting of redundant feedback in the form of visual (see DR-2.2), auditory (see DR-2.2.5), and haptic effects (see DR-2.2.5), can be used to reinforce concepts while increasing the simulation appeal and immersion feeling. Practical examples for this prototype are provided by the experts and reported below.

> E3: Provided information could be more, notes could be taken specifically on the ramp to show what exactly the text refers to, like the handrails prosecute further than the last step, etc. That would create a more precise solution. [...] You could highlight on the ramp what is important about it, like the curbs, the handrails etc.

> E2: It would be better to have the barrier explanation without stopping to look at the barrier. A combination of both (animations and explanations) would be nice with also audio explanation.

DR-3.3.2: Delayed explanation – Delaying the provision of the textual information has a positive effect on fostering autonomous thinking, allowing the user to think on their own before being prompted with the explanation. Since this is a desired effect for educational simulations, providing hints and suggestions only on demand could be an alternative to simultaneous merging of communication means where all information is constantly available (see DR-3.3.1). As suggested by Expert3, information delivery in textual form can also be layered, introducing a short hint and providing details only when the user requires it.

> E3: More explanation is better. For example, you could give a hint of the problem, something such as "height", "light", "accessibility", and more explanation at a second level with details.

DR-3.3.3: Increased interactivity – The interactivity of the simulation stimulates the user reflection on the topic of the experience and increases their immersion. As suggested by Expert3, allowing the user to choose and place solutions in the virtual environment could help them recognise the advantages and limitations of different options while pondering the difficulties of solving accessibility issues by modifying existing buildings.

> E3: In the future you could provide ramps and ask the user to place the solution themselves.

6.3.4 Reflection

DR-4: Reflection – This section explores suggestions to improve the user's retention and elaboration of concepts displayed in the educational simulation.

DR-4.1: Memory – Aiding memorisation of concepts and retention of information is crucial to create an effective educational tool. Together with limitation of distractions (see DR-2) and clarity of concepts (see DR-3), information density (see DR-4.1.1) and provision of overviews (see DR-4.1.2) affect information retention during and after the experience.

DR-4.1.1: Information Density – Building a short and concise simulation with a limited number of new concepts positively affects the user's capability of remembering the displayed information. Significative examples should be chosen and displayed minding the target audience's need for details (see DR-3.2.3). Extending the duration of the experience with redundant information should be avoided to prevent confusing and overloading the participants. As suggested by Expert5, fifteen minutes for the experience can be considered a reasonable length.

> E5: It's good the amount of time needed for the experience. It's good to be able to remember all.

DR-4.1.2: Overview – Providing explanations (see DR-3.2) and summaries can reinforce understanding and retention of concepts. Additionally, reiterating information already provided in a schematic and concise version aids the user in revisiting thoughts and building an overview of the presented topic. Expert3 provides an example for the prototype of this thesis.

> E3: You could add a game effect in the tool at the end with tasks, barriers, current solution, and the improved solution without the barriers. With current solution I mean the current way of doing stuff, like where the ramp is missing, the alternative to leave the building is through the sliding doors and the outside slope.

DR-4.2: Generalisation – In the context of an educational tool to sensitize about architectural barriers and solutions, enhancing the ability to generalize concepts improves users' ability to identify accessibility issues in their daily lives. Facilitating the generalization of concepts is supported by fostering spaces for imagination and providing comprehensive insight into the topic. Both free exploration (see DR-4.2.1) and textual explanations (see DR-3.2) allow room for users' imagination, while presenting a variety of issues (see DR-4.2.2) and offering multiple solutions (DR-4.2.3) promote the recognition of key features.

DR-4.2.1: Free exploration – Offering opportunities for users to engage their imagination and critical reasoning aids in generalizing concepts. Allowing freedom to autonomously explore the environment, seeking out architectural barriers without prior knowledge of their location, encourages users to assess their surroundings critically, probing and questioning what they observe. To maintain a balance during free exploration, the architectural barriers they are expected to find must be easily recognisable when in sight (see DR-1.3) as suggested by Expert5.

> E5: Different target groups of barriers could be highlighted better. While looking around with a target group in mind you can imagine other problems and solutions.

DR-4.2.2: Multiple Issues – Incorporating in the experience a wide range of examples addressing different types and variations of architectural barriers assists the users in recognising the relevant features and extending their understanding outside the simulation. Multiple architectural barriers belonging to a variety of categories should be introduced in the simulation to foster reflection on a variety of issues as suggested by Expert1.

> E1: The simulation could be theme based, to not overlook other disabilities other than wheelchair users. You could diversify the barriers more and give the impression of a crowded area.

DR-4.2.3: Multiple Solutions – Presenting a single predetermined solution for each architectural barrier may restrict the user's ability to generalize and envision similar adaptations suitable for slightly different contexts. To aid generalisation of solutions, multiple options displaying a range of variations could be provided. Additionally, users could be tasked with selecting and placing the best solution for the issue among the presented options, as suggested by Expert3.

> E3: It is nice, but more info and examples could be interesting, or more solutions for each barrier could be displayed. For example, a sliding display for the first barrier, some light settings for the book, and multiple ramps configurations could be presented as solutions. [...] You can highlight the barriers and make the user find or choose solutions while learning about regulations [...]. You can use it to actually change a place trying options to see if they're actually accessible with VR.

Chapter 7

Discussion

7.1 Answering The Research Questions

To answer the research questions (see Section 1.3), We designed (see Chapter 3) and built (4) a prototype VR simulation to educate about architectural barriers that was evaluated by architecture and accessibility experts (see Section 5.1). The feedback was analysed (see Section 5.2) to identify the recurring themes (see Section 6.2) and create design recommendations (see Section 6.3) for future simulations in a similar context.

7.1.1 First Research Question

The first research question (see Section 1.3) addresses the impact of juicy design elements (see Section 2.4) on the interaction of the participants with the virtual environment and the communication of architectural barriers.

The realistic environment (see Section 4.3) successfully serves as familiar background (see T-1.1) to contextualise the architectural barriers in public spaces commonly frequented by students and staff within the KIT university campus (see DR-1.1).

The playful highlighting mechanisms (see Section 4.7.1), used to signal the presence of architectural barriers within the virtual environment, were successful in the task of promoting engagement with the desired targets (see T-1.2). From the TAemerged that the introduction of juicy highlighting effects boosted the visual appeal of the simulation and created a captivating contrast (see T-1.1.1) with the realistic surroundings (see T-1.1). The contraposition had a positive effect on the users' curiosity (see T-1), piqued by the embellished objects, and attention (see T-2), drawn toward the desired components (see DR-1.3).

The animations (see Section 4.7.2), used to explain the issues introduced by the architectural barriers and show a possible solution, were partially successful in conveying the messages (see T-3.1). Increased precision would be necessary in applications aimed at architecture and design students (see T-2.2.1). Additionally, the animations that introduced limited variations of the object, especially when associated with less common or intuitive architectural barriers (see T-3.1.1), were found not noticeable enough and therefore difficult to understand, making the textual explanations (see T-3.1.2) necessary. On the other hand, slower and more extensive animations were found informative and considered and added value to the simulation because capable of autonomously explain the solutions (see DR-3.1).

The juicy design elements added as effects to the animations (see Section 4.7.3) were instead considered distracting and overwhelming (see T-2.2.1), diverting the user's attention from the architectural barriers and their animation of the solution. More subtle embellishments should accompany the animations (see DR-2.2) to suggest that something happened but without diverting the user's attention from the target of the simulation.

Auditory cues (see Section 4.7.4) were perceived as missing (see T-5.1.2) and would have boosted clarity and understandability of the displayed animations Similarly, additional visual effects (see T-3.5) would have been appreciated to signal tasks termination (see DR-2.2.5).

7.1.2 Second Research Question

The second research question (see Section 1.3) investigates the influence of the design elements within this prototype on both UX and reflection regarding architectural barriers.

According to the SDT, fulfilling all users' psychological needs for competence, relatedness, and autonomy, improves UX and positively contributes to engagement and intrinsic motivation (see Section 2.4).

Competence denotes the user's perceived mastery and effectiveness in navigating the simulation, ultimately enhancing their enjoyment and engagement. The simple and intuitive control system (see T-2.3.1.2) and interaction mechanism of the simulation (see T-2.3.1.1), paired with the possibility for users to familiarise themselves with the simulation's mechanics during a tutorial (see T-2.3.1), favoured the participants confidence. Similarly, the highlighting mechanism (see T-1.2) was effective in directing the users toward the interactable objects in sight without affecting the users' autonomous exploration. On the other hand, the effects lacked a clear mechanism to suggest events termination (see T-3.4) and the absence of a task system (see T-3.5) caused confusion, hindering competence. Auditory cues (see T-5.1.2) were perceived as missing even if present and therefore, they did not contribute to understanding. The animations (see T-2.2.1) demonstrated to have a positive effect on competence because instructive about architectural design issues and possible solution (see T-3.1). Nevertheless, the absence of references to aid identifying and comparing states of the barriers (see T-3.1.1) paired with invasive effects (see T-2.2.2) negatively affected understandability of concepts in some cases. The textual explanations (see T-3.2) provided valuable feedback and important additional details that supported understanding, but the difficulty to read in VR (see T-2.1.2) and the absence of auditory explanations (see T-5.1.1) constituted an obstacle for comprehension.

Autonomy denotes the users feel of control on their gaming experience, enabling them to engage in a way that feels personally meaningful and satisfying to them. It enhances user engagement, motivation, and immersion by promoting a sense of ownership and agency over the experience. The simplicity of the control system and the provided familiarisation environment of the prototype (see T-2.3) supported user autonomy during the environment exploration. Freedom of choice was provided by limited requirements within the experience that allowed participants to roam the virtual environment at their own rhythm while exploring the architectural barrier in any desired order. Significative interactions also improved autonomy, allowing the user to trigger modifications to the space and improve the accessibility of the environment (see T-3.1). Even though the feature was appreciated, increased interactivity was suggested as a mean to improve immersion and motivation. As highlighted by the experts, providing opportunities to choose between multiple solutions (see T-5.3) or personalising settings to fit the participants preferences (see T-5.5) would contribute to autonomy and therefore improve UX.

Relatedness denotes a sense of connection, social interaction, and belonging within the environment that contributes to engagement, satisfaction, and enjoyment. In this prototype, multiplayer options and Non-Player Characters (NPCs) were not introduced (see Section 3.4.5), leaving the sense of connection, engagement, and emotional attachment to the virtual world as only components of relatedness. The virtual environment of the prototype (see T-1.1) was highly realistic, and the experts recognised feeling a positive connection with the relatable and familiar background while being attracted by the highlighting surrounding the architectural barriers (see T-1.2). The possibility to freely explore the virtual building and the interactivity with the architectural issues (see T-3.1) positively contributed to relatedness allowing the participants to discover and influence their surroundings. Nevertheless, relatedness could be further increased by introducing social interactions within the prototype. In fact, the presence of a crowd (see T-5.3.1) was perceived as missing and experts suggested to introduce NPCs interacting with the barriers to provide comparisons for changes recognition and demonstrating issues caused by architectural barriers (see T-5.2.2). Even though the implementation of the last suggestion would go against the principles of this prototype, components contributing to relatedness should be further investigated to improve UX (see Section 8.2).

Reflection is the cognitive process through which learners deepen their understanding, integrate new knowledge, and apply it to real-world contexts. It involves revisiting thoughts that challenge the current understanding of a subject, encouraging individuals to view the subject from different perspectives, which can lead to transformative thoughts or behaviours (see Section 2.4). According to the TAresults (see Section 6.2), reflection during the experience (see T-4) is prompted by spaces for autonomous thinking, such as the opportunity for free exploration of the environment while searching for architectural barriers (see T-4.2), and the time gap between the presentation of animated solutions and their explanation (see T-4.1). Interacting with the architectural barriers and modifying the environment to solve accessibility issues also fosters a deeper understanding of inclusion limitations and prompts reflection on accessibility challenges in public spaces, along with potential solutions to address them (see T-3.1). The prototype enables participants to integrate their knowledge of architectural barriers with insights gained from the VR simulation, facilitating connections between different concepts and practical applications, thereby improving understanding (see T-4.1). However, better support for generalization is needed in the future (see T-4.2), as animations, especially in limited amounts, depict specific issues that may hinder participants' ability to extend their newly acquired knowledge outside of the VR experience. Furthermore, the simulation has the potential to trigger transformative thinking (see T-4.4) by focusing on solutions to architectural barriers without demonstrating the limitations introduced by poor design choices. Nevertheless, the analysis suggests that disability simulations (see T-5.2), such as perspective-taking (see T-5.2.1) and struggle simulation (see T-5.2.2), are still considered valuable tools for fostering understanding and increasing awareness of architectural barriers and accessibility.

7.2 Literature Connection

In this section we discuss the findings of this study (see Section 6.2) in relation to existing theories (see Chapter 2). The results of the TA suggest how the approach of this study is a valid alternative (see Section 7.2.1) to simulating disabilities to foster empathy (see Section 1.2) and has potential as an educational tool (see Section 7.2.3) to educate about accessible design (see Section 2.2). Section 7.2.3 reports the findings emerged from the analysis in relation to the framework for educational simulations (see Section 2.3) used as guideline for this study.

7.2.1 VR Simulations to Foster Empathy

The findings of this study confirm that, as suggested by (Dick, 2021), VR simulations have advantages with respect to other two-dimensional teaching tools (see T-4.3) and the prototype demonstrates potential to be valid educational experience (see T-6.2).

A prevalent method used to raise awareness and foster empathy toward disabled people is the prospective-taking approach that simulates the experience of being disabled when completing tasks [10] or experiencing virtual environments [8] [9]. The approach is still believed to be valid and effective (see T-5.2.1), but the findings of this study (see T-4.4) highlight how the new approach based on solutions (see T-3.1) has potential to expose how environmental barriers around people with disabilities disable them [15].

7.2.2 VR Simulations to Support Architectural Design

The results of the study suggest that the concepts of this prototype have potential in contributing to architecture and design students' education about accessible design (see T-6.2) confirming that VR tools in architecture design education can be attractive and stimulating (see T-1).

The issue reported by [21] suggests that the integration of VR software in architecture education curriculum is at risk of being confusing and inefficient because of the complexity of the software available. The results of this study confirm the importance of simple setup (see T-2.3) and intuitive commands (see T-2.3.1) to build a valuable educational tool on accessible design (see T-6.2). Additionally, integrating visual, textual (see T-3.3), and auditory (see T-5.1) cues would facilitate understanding of the illustrated topics.

7.2.3 Educational Simulations

The study "A Framework for the Use of Immersive Virtual Reality in Learning Environments" [22] was used as guideline during the definition of the prototype's features (see Section 2.3). This section discusses how the findings of the TA(see Section 6.2) can be mapped back to the indications provided to build an effective learning environment.

The CTML [22] is a framework for designing effective multimedia learning environments and is based on three principles of learning: dual coding theory, limited capacity theory, and active processing theory.

According to the dual coding theory, people process information in two different channels, visual and auditory. This study focused on visual communication means (see Section 3.5.4), but the absence of auditory cues (see T-5.1.2) and explanations (see T-5.1.1) was reported as an evident limitation of the prototype (see Section 8.2).

The Limited Capacity theory suggests that people have a limited capacity for information processing, so instructional material should be designed to avoid overloading learners' cognitive resources. Similar results concerning the setup (see T-2.3) and features of the prototype emerged from the analysis. The simple controls system (see T-2.3.1), the realistic environment (see T-1.1), and the disappearing highlighting effects (see T-1.2) avoided distracting the users during the experience. Conversely, the chosen effects played contemporarily to the animations (see T-2.2.1) and the necessity to read in VR (see T-2.1.2) risked overloading the participants' cognitive resources hindering their learning process.

The Active Processing theory suggests that learning is an active process that involves constructing mental models, so instructional materials should be designed to encourage learners to engage with the material and make connections between new and existing knowledge. The results of the study similarly suggest that interaction with the architectural barriers aids understanding (see T-6.1), retention (see T-4.3), and generalization of concepts (see T-4.2).

Additionally, the study on IVR in learning environments identifies three key features of simulation technology: interaction, immersion, and imagination.

Interaction refers to the ability of participants to actively engage with the virtual environment and was a fundamental concept of the developed prototype (see T-6.1). During the experience, users successfully learn about barriers by triggering modifications to the space displaying solutions (see T-3.1) and textual explanations (see T-3.2).

Immersion refers to the sense of presence and realism that the virtual environment creates and was supported by the realistic and familiar environment (see T-1.1) that could be explored using a natural and intuitive navigation system (see T-2.3.1).

Imagination refers to the human mind's capacity to perceive non-existent things and can be prompted by spaces for autonomous thinking, like freely exploring the environment while looking for architectural barriers (see T-4.2) and delaying the presentation of explanations to the animated solutions (see T-4.1). From the analysis emerged that providing more examples of accessibility issues (see T-5.3) would improve the participants' generalization capabilities (see T-4.2) and having tasks to direct the user (see T-3.5) when looking for the architectural barriers would be an improvement even if it restricts their freedom to explore.

The recommendations for educational simulations (see Table 2.1) were applied during the design of this prototype and the feedback concerning the suggestions can be found in Table 7.1.

Suggestion	Feedback
"Learning first, immersion second"	The level of immersion provided by VR proved to be sufficient. Contributors were the level of accuracy of the reproduced KIT cafeteria that created an easily relatable environment (see T-1.1) and the simple and intuitive control system suitable also for participants new to VR (see T-2.3.1).
"Provide learning relevant interactions"	The minimization of interactions, limited to the navigation menu and the architectural barriers, positively affected the participants ability to focus on the accessibility issues, but multiple implementation choices proved to be distracting (see T-2). The need to read in VR (see T-2.1.2), the positioning of the textual explanations (see T-2.1.1), the explosive effects triggered alongside the animation (see T-2.2.1), the imprecision in the displayed solutions (see T-2.2.2), and the difficulty to interact with some of the components (see T-2.3.1.1) negatively affected the participants attention on the desired events triggered by the interactions. The opportunity to master the control system during the pre-training opportunity provided by the tutorial helped minimising distractions during the successive scenes of the experience (see T-2.3.1).
"Segment complex tasks in smaller units"	The analysis suggested that a system of tasks should be introduced to guide the participants during the exploration of the environment (see T-3.5), especially in case of a larger number of architectural barriers being displayed (see T-5.3).
"Guide immersive learning"	Feedback on guidance suggested that more indications on what to expect (see T-3.5) and when to consider tasks as terminated (see T-3.4) would be an improvement. Reminders on the participant's goal and summaries of the discovered information would aid recall and prevent cognitive overload (see T-4.3). On the other hand, spaces for autonomous thinking, like the delay in providing explanations (see T-3.3.2), were successful in prompting reflection (see T-4.1).

	From the gathered insight we conclude that information on the experience structure should be clear, abundant, and redundant, while guidance on the features that have an educational purpose should be provided in the form of reinforcement. By delaying explanations, the learner's autonomous thinking process is incentivized while correct understanding is still ensured.
"Build on existing knowledge"	This prototype was experienced by experts in the context of architecture and accessibility. From the analysis of their feedback emerged that participants might have varying levels of background knowledge depending on their previous experiences and the addressed disabilities (see T-3.1.2). The kind of chosen architectural barriers (see DR-3.1.4) and the number of inserted details and explanations (see DR-3.2.2) must be tailored to the target audience and desired learning outcome (see T-6.2).
"Provide constructive learning activities"	The analysis suggests that the prototype VR experience has potential as an educational tool to sensitise and teach about architectural barriers and accessible building design (see T-6). The employment of VR is expected to positively affect recall of concepts with respect to two-dimensional teaching material (see T-4.3). The careful introduction of playful effects can improve the simulation visual appeal while contributing to the participants comprehension process, making learning more enjoyable (see T-2.2).

Table 7.1: Feedback on recommendations to build an educational simulation [22]

7.2.4 Juiciness and Embellishments in VR

The goal of this project is to assess the effects of visually engaging design elements on UX, understanding, and reflection on architectural barriers and accessibility issues (see Section 7.1).

The results of the TA (see Section 6.2) suggest that, as highlighted by [25], juiciness can improve user experience in non-gaming settings by satisfying all the user's basic psychological needs as defined in the SDT (see Section 7.1.2). Additionally, the findings of this study confirm that juiciness and VEs, as shown by [23], improve UX in terms of visual appeal and related constructs such as curiosity, immersion, and meaning (see Section 7.1.2). On the other end, though, VEs should be balanced by other design elements to avoid overwhelming users and distracting them from the overall experience.

The studies indicated that the incorporation of visually engaging design elements in diverse contexts where user engagement is essential can significantly impact UX, influencing motivation, curiosity, and immersion. The intensity of these design elements can evoke positive feelings or, in some cases, become overwhelming. This study confirms that these phenomena apply also to the realm of VR simulations, where effects hierarchy can negatively affect attention (see T-2.2) and hinder understanding.

Additional constructs that can be included within the concept of redundant feedback are the so-called Haptic Embellishment (HEs) and juicy haptics [27]. This study introduced HEs to the interaction mechanisms, but no conclusion on their efficacy in enhancing the simulation enjoyability, aesthetic appeal, immersion, and meaning can be drawn from the results.

7.3 Practical Implications

To provide practical applications of the theoretical results, design recommendations (see Section 6.3) for future educational applications on accessible buildings design were extracted from the identified themes (see Section 6.2.2). The design recommendations provide suggestions on how to develop the concepts of this prototype to create applications tailored to different target audiences. The recommendations collected from this study highlight week spots and positive features of the prototype developed for this study. They should be used if developing the presented concepts toward a specific target audience (see T-6.2) to tailor the experience to the different participants needs. For example, if developing an educational tool to teach about accessible design for an architecture curriculum, one could check in the recommendations which variables are relevant for architecture students. Being mindful of the findings and suggestions extracted from this study would avoid making known mistakes and support developers in designing suitable of features.

The final recommendations contain quite specific information relevant to applications built with similar intentions to the ones of this prototype (see Section 1.3). In case of similar projects or expansions of this prototype built to address its limitations (see Section 8.2), the recommendations are directly applicable to the design of the simulation structure (see DR-3.3), control system (see DR-2.3.3), animations (see DR-3.1), effects (see DR-2.2), and textual (see DR-3.2) and auditory explanations (see DR-2.1.3). For other educational VR tools, relevant insight can be found on more general aspects regarding factors like simulation setup (see DR-2.3), virtual environment reproduction (see DR-1.1) and readability in VR (see DR-2.1).

Chapter 8

Conclusion

This chapter draws the conclusions of this study providing a summary of this thesis (see Section 8.1), detailing the main limitations of the study (see Section 8.2), highlighting the contributions to the field (see Section 8.3) and suggesting areas for future research (see Section 8.4). Section 8.5 concludes with some final words.

8.1 Summary of the Study

This study explores the potential of VR to convey information about architectural barriers exploring the effect different communication means have on the users' interest, comprehension, and reflective process (see Section 1.3).

In the context of sensitisation about architectural barriers, VR is often used to simulate the feeling of being disabled (see Section 2.1.2) which can result in the confirmation of stereotypes (see Section 1.2). This study investigates an alternative approach where information about accessibility issues is conveyed focusing on possible solutions that create universally accessible environments (see Section 1.2). The effectiveness of embellishments and juicy design (see Section 2.4) was compared to the efficacy of textual explanations in communicating architectural barriers, improving UX, and prompting reflection, as demanded by the research questions (see Section 1.3). To allow the comparison of the communication means, we created a prototype VR simulation set in a replica of the KIT campus' cafeteria (see Section 3.3).

The simulation was experienced and evaluated (see Section 5.1) by five experts with a background in architecture, accessible design, and assistive technologies (see Section 6.1). The experts provided feedback on the simulation's appropriateness, informativeness, and completeness, focusing on the effectiveness in conveying information with different methods (see Section 3.1). The feedback on the prototype's features was analysed using TA [29] (see Section 5.2) to identify recurring patterns (see Section 6.2) and provide design recommendations for similar applications in the future (see Section 6.3). The results of the study are discussed in Chapter 6 to answer the research questions (see Section 7.1), draw connections with the existing literature (see Section 7.2), and illustrate the practical implications of this study (see Section 7.3).

The analysis revealed that the approach utilized in this study has potential to shift participants' focus (see T-4.4) from viewing disabilities as limiting to recognizing architectural barriers as the primary impediments and realising the importance of solution-finding. It also emerged that juicy highlighting mechanisms (see T-1.2) that have a contrasting aesthetic (see T-1.1.1) with respect to the background environment (see T-1.1) successfully improve the simulation visual appeal while piquing the users curiosity (see T-1). On the contrary, predominant embellishments (see T-2.2.1) played simultaneously to the animations (see T-2.2.2) can be distracting (see T-2.2) and confusing. The textual explanations provide good feedback and reinforce understanding (see T-3.2) but the low readability in VR can be overwhelming for participants (see T-2.1.2). Merged communication means (see T-3.3) that include animated, textual, and auditory cues (see T-5.1) are expected to boost comprehension (see T-3.3.1) but delaying explanations (see T-3.3.2) should be considered to foster autonomous thinking and prompt reflection (see T-4.1).

8.2 Limitations

This section presents the primary limitations of this study which include the integration of a restricted number of barriers and disabilities, the limited usage of the auditory channel, the arbitrariness of using textual explanations as baseline, and the decision prototype validation by means of expert interviews.

Restricted number of barriers and addressed disabilities (see T-5.3) – Due to time constraints, some restrictions of the project's scope were made. During the screening process of the KIT university cafeteria, a large number of architectural barriers were identified, but only three were selected to be integrated into the final prototype (see Section 3.4.5). The choice of reducing the amount to three components was arbitrary and might have affected the experts' feedback during the evaluation of constructs related to the perception of the simulation's extension (see T-5.3), complexity, and duration (see T-4.3). Because of the limitation of the displayed architectural barriers, the range of involved disabilities decreased to two and the reduced selection is not sufficient in the context of a tool for educational purposes. Additionally, the absence of a crowd in the simulation greatly affects the perception of the reproduced virtual environment (see T-5.3.1), leading to a possible distortion of the displayed architectural barriers' perception. The removal of people from the simulation reduces the authenticity of the reproduced cafeteria, hinders relatedness (see Section 7.1.2), and prevents participants from understanding the worsening impact of crowds on accessibility issues.

Limited usage of auditory channel (see T-5.1) – This project's scope was limited to the investigation of the visual channel of communication by introducing neutral and minimalistic sounds as additional feedback to the interactions. According to the dual coding theory (see Section 2.3) and in accordance with what emerged from the analysis (see T-5.1), more significant acoustic cues should have been introduced to enrich the feedback provided when interacting with the embellished barriers and auditory explanations of the architectural issues should have been provided as an alternative to the textual boards.

Textual explanations as baseline – The choice of textual explanations as baseline (see Section 3.6) to understand the effects of juiciness and VEs was discussed among the members of the research group and deemed reasonable, but it lacks validation from literature sources. Better alternatives might have been available, leading to different results from the experts' evaluation.

Experts' feedback for validation – Due to time constraints, this prototype was validated by means of expert interviews (see Section 5.1), but additional relevant insight could be gathered from testing the simulation with architecture students or the general population.

Subjectivity of the study – The TA method used to organise information collected during the experts' interviews (see Section 5.2) and the extraction of design recommendations (see Section 5.3) from the themes were highly subjective processes. Even though a lot of time was dedicated to these phases with the best intentions of respecting every step of the method, different choice of participants (see Section 5.1.3), different questions asked during the interviews (see Section 5.1.3), and a different analysis process (see Section 5.2) would have led to different feedback and potentially providing additional insight and modifying the results.

Low Abstraction of the recommendations – To avoid creating vague design recommendations that would have been difficult to apply even to a simulation similar to the one of this study, a low level of abstraction was applied to the concepts (see Section 6.3). This could lead to recommendations scarcely applicable to educational simulations in contexts different to the one presented in this thesis impacting the broadness of their effectiveness and usability. Additionally, the lack of higher-level abstraction might limit the transferability of findings to broader applications within the field of architectural barrier education, warranting further exploration into more generalizable principles and recommendations.

8.3 Contributions to the Field

The typical approach to sensitise about architectural barriers has clear limitations (see Section 8.2) and the findings of this study suggest that the adopted method has potential in fostering reflection (see Section 7.2.1) and could constitute a valid alternative to disability simulations (see Section 2.1.2) that should be further investigated. Due to the limitations of this thesis (see Section 8.2) more complex systems should be built and assessed for future research (see Section 8.4) but hopefully the conducted analysis of the experts' feedback (see Section 6.2) and the extraction of design recommendations (see Section 6.3) will help developers take informed decision when facing similar design and implementation challenges. In relation to the literature, we hope that the similarity in findings concerning the positive effects of juicy design (see Section 7.2.4) will incentivize developers to introduce VEs in educational simulations to improve UX and foster reflection.

8.4 Suggestions for Future Research

This project provides a detailed screening of the architectural barriers present in a university building, a realistic virtual environment reproducing a section of an existing building (see Section 3.3), and a new approach to raising awareness about architectural barriers and accessibility issues using VR (see Section 1.2). The findings of this study focus on the effects of juicy design elements and VEs on barriers communication, UX, and reflection on accessibility issues (see Section 7.1).

Many possibilities are available for future development and research on these concepts. This section highlights some possibilities that emerged during the development of this prototype and includes some suggestions gathered from the literature review and the experts' feedback.

The prototype featuring three barriers in two different variations could be used, for further development in the context of educational tools on architectural barriers, by integrating engaging embellished animations and textual explanations for additional insight (see T-3.3). More barriers and target groups could be included (see T-5.3), to provide a more comprehensive experience, and the concept of crowd could be incorporated as a barrier itself or as an exasperating feature of other issues (see T-5.3.1).

Three main future applications were envisaged for this prototype, namely: the creation of a tool to raise awareness about architectural barriers for the general population, an educational experience for architecture and design students to learn about accessibility guidelines, and a training simulation to inform the personnel that works with disabled individuals (see T-6.2). As suggested by the findings of this study (see Section 6.2) and the extracted design recommendations (see Section

6.3), different accuracy levels in representing the accessible solutions should be used depending on the target audience (see T-6.2). Additionally, a task-based approach (see T-3.5) could be adopted to guide the users within the environment, direct them toward the barriers, and to position them at the correct distance and angle.

In the context of a tool for the general population, a larger number of architectural barriers, targeting a wider range of disabilities, could be included to sensitise about the frequency and variety of possible accessibility issues in public spaces. Gamification elements could be introduced to guide and motivate the user to identify all the architectural barriers (see T-3.5) present in the environment and both embellishments and textual explanations could be leveraged to provide information and explanations (see T-3.3).

In the context of an educational tool for architecture students, more interactive mechanisms could be introduced. To maintain the focus of the simulation on the resolution of accessibility issues due to the building's design, multiple solutions could be provided to the learner that would be required to choose and position them themselves (see T-5.3). The development would allow students to interact with the environment and learn about the advantages and disadvantages of possible solutions in a virtual setting before applying the acquired skills in their future careers.

As a training tool, the virtual experience could be used to highlight issues faced by disabled people to raise awareness on past mistakes and avoid repeating them in the future by suggesting alternatives. Specific features could be introduced to provide specialised insight depending on the environment to make workers more aware of the issues and good practice examples (see T-6.2).

8.5 Final Words

"Accessible design is currently in an age of implementation" [7] and devising ways to educate about its importance and regulations is fundamental to contribute to the process. This study reveals the promising potential of VR as an educational tool for raising awareness about architectural barriers and promoting solutions-focused thinking. By exploring different communication methods within VR simulations, we analysed their effectiveness of conveying information about accessibility issues while minimizing the reinforcement of stereotypes. While juicy design elements can enhance engagement, careful balance is necessary to avoid distraction. There are multiple opportunities to expand the scope of this simulation, tailor the experience to diverse audiences, and incorporate gamification elements for increased engagement. Despite certain limitations, this research underscores the transformative impact VR can have in fostering inclusive design principles and empowering individuals to create more accessible environments.

It was found that the chosen juicy design elements and the embellishments applied to the architectural barriers in the virtual environment have a positive effect on drawing the user's attention towards the desired targets and sparking their curiosity on the presented information but can appear exaggerated and distracting when paired with the animations that showed the solution of the architectural design issues.

The realism of the KIT cafeteria virtual replica, combined with the intuitive and user-friendly design of the interaction system, proved to enhance the users' immersion feeling during the simulation, minimizing distractions, and allowing the architectural barriers to be the focus of the experience. Additionally, the contrast between the realistic background and the enrichments used to highlight the architectural issues provided clarity on the task of finding the barriers and was successful in sparking the users' curiosity, increasing their motivation to explore and understand the highlighted components.

Furthermore, the possibility of seeing alterations of the space to fit accessible solutions to preexisting issues proved to be a valid tool to shift the participants' focus from the difficulties faced by disabled people to the potential of the design choices in creating inclusive spaces.

This study showed that the limitations of using VR to simulate the experience of being disabled as a tool to raise awareness and educate about architectural barriers can be overcome by this different kind of simulation. In this project, the participants were not asked to identify themselves as disabled but experienced the simulation without impairments while being educated on having a different perspective on the surrounding environment.

The prototype featuring three barriers in two different variations could be used, for further development in the context of educational tools on architectural barriers, by integrating engaging embellished animations and textual explanations for additional insight. More barriers and target groups could be included, to provide a more comprehensive experience, and the concept of crowd could be incorporated as a barrier itself or as an exasperating feature of other issues.

The created environment and the developed design suggestions could be used in the future for a broader project with architecture students or the general population. As suggested by the findings of this study, different accuracy levels in representing the accessible solutions should be used depending on the addressed group. Additionally, a task-based approach could be adopted to guide the users within the environment, direct them toward the barriers, and to position them at the correct distance and angle.

Appendix A

Architectural Barriers Checklist

This section of the appendix contains the checklist document created and used to assess the accessibility of the cafeteria building. The document is an improved version of the one presented in the article "Architectural Barriers to Persons With Disabilities in Businesses in an Urban Community" [1], where additional considerations from the accessibility guidelines provided by the BMUB Federal Ministry [16] were added.

Accessibility checklist

Building: ____

Room: ____

Time: ___/___ /______; h ____ : ____

Legend:
- ✔ → Property is satisfied
- ✘ → Property is NOT satisfied
- ☐ → Property cannot be evaluated

Numbers: Numbers are used to specify to which extent a property was satisfied in case of yes/no answer proving to be insufficient. [1=not at all; 5=completely]

Entrance and exit

Reachability: (..)

☐ On the same level ☐ With ramp ☐ Inaccessible

Ramps: (..)

☐ Appropriate slope ☐ Handrails on both sides ☐ Free handrails

* max slope ratio: 1:12 or 1:20

Threshold: (..)

☐ Low threshold ☐ Accessible alternative

* max threshold height: 1.27 cm (0.5 inch)

Space: (..)

☐ Sufficient door width ☐ Obstruction free ☐ Manoeuvrability space

* min door width: 81-91 cm

Doors: (..)

☐ Automatic doors ☐ Always-open doors ☐ Manual doors

In presence of automatic doors: (..)

☐ Doors remain open long enough ☐ Well calibrated sensor for different heights

In presence of manual doors: (..)

☐ Lever-style door handles ☐ Light weight doors

Mats: (..)

☐ Slip resistant ☐ Securely fastened to the floor ☐ With bevelled edges

Flooring: (..)

☐ Slip resistant ☐ Even surface ☐ Smooth surface

Lighting: (..)

☐ Minimum shadows and glare ☐ Well-lit during the day ☐ Well-lit at night

Figure A.1: Page 1 of Accessibility Checklist used to assess the cafeteria building

<u>Handrails</u>

Location: (……)

☐ Along stairs ☐ Along ramps ☐ Along slopes

Characteristics: (………)

☐ Graspable (diameter) ☐ Multiple heights

<u>Facility reachability</u>

Parking spaces: (………)

☐ Close to the building entrance

☐ Provided with appropriate signage and markings

☐ Wider than standard parking spaces

☐ Provided with adjacent access aisles for wheelchair users

☐ Provided with tactile paving to the facility

Bus stops: (……)

☐ Close to the building entrance

☐ Provided with appropriate signage and markings

☐ Provided with tactile paving to the facility

By feet: (……)

☐ Sufficiently wide walkways

* min walkways width: 91-122 cm (36-48 inches)

Walkways clearance from:	☐ Protruding objects	☐ Overhanging elements	☐ Obstacles
Surfaces condition:	☐ Smooth	☐ Even	☐ Slip-resistant
Level differences:	☐ Low thresholds	☐ Adequate slopes	☐ Present curb-cuts

* max threshold height: 1.27 cm (0.5 inch)

* max slope ratio: 1:12 or 1:20

☐ Walkways provided with tactile paving to the facility

☐ Walkways provided with guardrails to prevent accidental falls

☐ Adequate lighting on the pathways

☐ Provided seats/resting areas

☐ Adequate water draining

☐ Sufficient shaded areas

Figure A.2: Page 2 of Accessibility Checklist used to assess the cafeteria building

Signage and wayfinding

Signage location: (..)

☐ Entrances ☐ Elevators ☐ Restrooms ☐ Important locations

Signage completeness: (..)

☐ Directional indicators ☐ Room names/numbers

☐ Accessible routes information ☐ International accessibility symbols

Signage visibility: (..)

☐ Large fonts ☐ High contrast ☐ Braille/tactile option

Wayfinding information clarity: (1=low understandability, 5=perfectly clear) ____

(Details: ....)

☐ Presence of tactile paving on walkways

Elevators and Lifts

☐ Present at intuitive locations

☐ Sufficient size to accommodate mobility devices

* min door width: 91-107 cm (36-42 inches)

☐ Provided with handrails or grab-bars inside

☐ Provided with door sensors and automatic doors

☐ Provided with enough manoeuvrability space in front

Controls characteristics: (..)

☐ Easily reachable ☐ Operable with varying abilities

☐ Tactilely discernible buttons ☐ Clear and visible signage

☐ Braille information available

Audio indicators for: (..)

☐ Floor number ☐ Door movements

Figure A.3: Page 3 of Accessibility Checklist used to assess the cafeteria building

Lighting

Shadows and sharp contrasts: (...)

☐ Uniform lighting distribution ☐ Even lighting level across the entire space

☐ Ensure that lighting does not directly shine into occupants' eyes

[Nota 1. to avoid glare, shadows, or areas of excessive brightness contrast within a space, to reduce eye strain, enhance visual perception, and ensure that individuals can see objects and navigate comfortably]

[Nota 2. minimization of variations and sharp contrasts between different areas]

Light fixtures: (...)

☐ Appropriate selection ☐ Appropriate placement ☐ Accurate colour rendering

☐ Accessible and user-friendly lighting controls (if present)

☐ Adequate exterior lightning

☐ Adequate lighting in correspondence of entrances/exits

☐ Adequate lighting in correspondence of stairs/steps

☐ Adequate illumination level according to the space use [*see guidelines]

Acoustics

☐ Appropriate background noise level

Sound insulation between different spaces: (...)

☐ Acoustic-rated doors ☐ Acoustic-rated windows ☐ Acoustic-rated walls

Reverberation control: (...)

☐ Wall coverings ☐ Curtains ☐ Acoustic ceiling tiles ☐ Absorptive panels

Sound reflection minimization: (...)

☐ Strategic placement of furniture ☐ Regular room shape ☐ Presence of soft surfaces

Assistive listening systems: (...)

☐ Personal amplification devices ☐ Induction loop system

☐ Infrared systems ☐ FM systems

Visual alternatives: (..)

☐ Visual displays ☐ Visual labels ☐ Visual alerts for emergency notification

Figure A.4: Page 4 of Accessibility Checklist used to assess the cafeteria building

Restrooms

Position: (...)

☐ Available on each floor ☐ Available at convenient locations ☐ Frequently present

Clearance: (...)

☐ Sufficient manoeuvring space in front of the entrance ☐ Sufficient turning space inside

Accessible furniture: (...)

☐ Provided with grab bars ☐ Accessible sinks ☐ Accessible toilet ☐ Wide door

Permission to use: (...)

☐ Free ☐ With key only

Furniture and Fixtures

☐ Desks/tables with knee and leg clearance

☐ Accessible counters height and depth

☐ Visual contrast in furniture elements

☐ Easily graspable objects

☐ Frequent possibility to rest (chairs/benches)

Adjustable: (...)

☐ Desks ☐ Work surfaces ☐ Seating height

Storage: (...)

☐ Reachable storage cabinets ☐ Reachable storage shelves ☐ Reachable storage areas

Circulation space: (...)

☐ Around tables ☐ Around chairs ☐ Around furniture

Flooring: (...)

☐ Contrasting colour ☐ Smooth ☐ Non-slip surfaces ☐ Even

Obstacles: (...)

☐ Ambient free from sharp edges ☐ Ambient free from protrusions ☐ Clear pathways

Stairs/steps: (...)

☐ Handrails on both sides ☐ Slip-resistant surface ☐ Tactile warning strips
☐ Colour contrast ☐ Rounded or bevelled nosing ☐ Consistent Rise and Run

Figure A.5: Page 5 of Accessibility Checklist used to assess the cafeteria building

Appendix B

Detailed Themes

T1: <u>Curiosity</u> – This category discusses the impact components have on the ability of the player to distinguish the targets they're supposed to direct their attention to and the background of the simulation. Capturing the player's attention and sparking their curiosity for the desired items is the first step toward meaningful interactions and satisfactory comprehension during the VR experience.

T1.1: Environment – This theme collects the considerations related to the role played by the developed background of the simulation in sparking the player's curiosity when entering the simulation.
The specific choice of environment didn't appear to be very relevant, while the reproduction realism was appreciated. The experts rarely mentioned the environment choice and recreation, but they were always neutrally or positively referred to.
E04: I was very focused on the items, It's not very important that it's the cafeteria itself.
E05: The cafeteria modelling is very nice. It still felt like the actual room, even with some abstraction. It feels like the real room; it's a good balance between details and abstraction.
<u>Conclusion</u>: The limited feedback on the environment and the lack of negative reactions suggest that the background served its purpose well, creating a familiar space that would not distract the players from the main focus of the experience.

T1.1.1: Contrast – This sub-theme highlights how the need for contrasting aesthetics emerged a relevant component to distinguish between targets (interactable objects) and background within the developed environment.
The contrast between the environment realism and the effects' magical appearance has a positive impact on the players' curiosity and focus.

Expert 01 suggests that said contrast has the capability of intriguing the user sparking their curiosity toward the highlighted items.
E01: The balance between the realistic environment and the less realistic effects is a teaser. They don't belong to the same aesthetic of signs, kinda like road signs on a street.
Expert 03 suggests that the distinction could be even more extreme by making everything dim or grayscale and leaving the architectural barriers in a brighter colour to direct the player's attention toward them.
<u>Conclusion</u>: the appreciation for the contrasting aesthetics suggests that the environment should remain realistic to be understandable to serve as a neutral background. On the other hand, the scene could function as a tool to direct the user's attention toward the primary subject of the experience sparking their curiosity with contrasting effects and directing them toward the targets.

T1.2: Highlighting – This theme describes the positive and negative impact the chosen barriers' highlighting system has on the player's ability to recognize the targets and their increase in curiosity and desire to investigate the items. The highlighting effect, consisting of a blue sparkling flame around each barrier, had the goal of incrementing the visual appeal of the simulation while directing the player toward the objects he was supposed to focus on and interact with. Expert 01 suggests that the specific highlighting effect might not fit everyone's taste in terms of beauty, but it still managed to spark their imagination with its magical appearance and intrigue them with its childish look.
E01: On appropriateness, it probably doesn't fit everyone's taste. It's not beautiful, at least, I didn't find it beautiful, but it's a bit like the magical imagination of a child. The childish look makes the person curious. [...] My reaction to the effects was to find them weird instead of beautiful, but still interesting with a childish Disney look.
The highlighting also proved to be helpful in suggesting the barriers' position and the fact that it disappeared when the player moved closer to the target was an appreciated feature.
E02: The highlighting flame it's good to attract the attention and it's good that it disappears.
E03: The highlighting is good, it makes the barriers easy to find. [...] You could highlight the barrier from afar, but then the user would have the task to find them again.
E04: For appropriateness I don't know ... but the highlighting is good, it helps identifying the items to interact, it's helpful.
<u>Conclusion</u>: the highlighting mechanism has a positive impact in drawing the players' attention toward the target objects tanks to their interesting and

curious appearance. But the highlighting shouldn't overshadow the actual barriers and the effect disappearance when in the target's proximity is an asset to avoid distracting the player.

T2: <u>Attention</u> – This category explores how different elements influence the player's ability to remain focused on the relevant aspects of each step of the experience while detailing what contributions end up being distracting.

T2.1: Boards – This theme describes how the concept of placing explanatory boards in the proximity of the architectural barriers was received by the participants and which factors affected their ability to concentrate on the content.
The boards scene is the third part of the experience, it comes up after the tutorial and the embellished scene. While the embellished scene explains the architectural barriers showing an animation of the solution and uses effects to reinforce it, the boards scene consists of textual explanations that appear next to the target when the player interacts with it. The goal of the boards is to give the user additional insight into the issue represented and provide confirmation of their understanding gained during the previous scene.
The boards scene first strikes off as "museum style" and suitable for educational settings. It is additionally described as blunt by Expert 1, as appropriate, static, and understandable by Expert 2, and it didn't stand out negatively according to Expert 5.
<u>Conclusion</u>: the concept of using explanatory boards next to the architectural barriers seems to be solid, unsurprising, and well-received by the users. Nevertheless, relevant issues emerged during the questioning. In particular, the chosen boards' positioning with respect to the barriers and the need to read text in Virtual Reality were repeatedly brought up as elements that negatively impacted the players' experience and ability to focus on the architectural barriers.

T2.1.1: Placement – This sub-theme highlights how the placement of the explanatory boards impacted the players' ability to focus on the explanation's content.
The explanation panels are positioned beside the architectural barriers and slightly turned toward the player's expected positioning for both the display device and the book, while for the stairs the text appears in the centre of the staircase without any rotation. The beside positioning was overall not appreciated and multiple issues were brought up.
The boards were easy to miss, especially if the player positioned themselves too close to the target and the resulting angle with respect to the panel made it difficult to read without re-adjusting one's position.

E01: The textual boards are positioned not in sight; they should be more in front. Both for the card machine and the book, the panels are easy to miss.
E04: Maybe the boards could be positioned at a better angle to read, because now the person needs to be in the good position to read. [...] It's just tricky to get the right angle to read.
Opposite to what was expected during the prototype's development, the players tended to position themselves too close to the targets, resulting in the panels being out of sight and at a poor angle for reading. 4 out of 5 experts positioned themselves very close to the barriers, especially in the case of the display device and the book, assuming a poor position to notice the boards appearance and read.
E03: Arriving too close to a barrier is a problem because you than need to go backwards to reposition yourself better to read.
The beside positioning choice has an additional undesired negative effect on the user's focus on the architectural barriers. The players' attention is drawn from the architectural barriers to the textual boards while reading, resulting in a sub-optimal configuration. The issue is to be considered very relevant because it was brought up by the second expert when answering the question about the general feeling on the application, suggesting that the problem was perceived as evident and urgent.
E02: The beside positioning of the boards moves the attention away from the barrier. It would be better to have the barrier explanation without stopping to look at the barrier.
Conclusion: I personally believe that explanation for the positioning close to the barriers resides in the size and level of detail of the barriers, that lead the experts to go very close to the smaller and more detailed objects to gather more insight on their nature. Additionally, and the user's familiarity with VR simulations impacts the player's ease to reposition themselves with respect to the boards. The beside positioning of the textual boards was detrimental to the goal of having the participants attention on the architectural barriers.

T2.1.2: Reading – This sub-theme details how the need to read in a VR setting could affect the players' ease of focusing on the explanation's content.
According to Expert 1, architecture professor specialised in buildings' accessibility, better formatting choices would improve the text readability making it more inclusive while also eliminating a possible distraction for architecture students.
E01: The readability of the panels would be better if the text was aligned

to the right instead of justified. This kind of imprecisions can be distracting for architecture students. [...] All uppercase writing of the boards' header makes it more difficult to distinguish the letters.
Additionally, text readability in VR is scarce and even though the chosen boards and font size were quite big, problems with readability still emerged. Expert 2 struggled through the boards section of the experience because she couldn't wear her glasses below the headset and reading proved to be a relevant obstacle. Similarly, Expert 5 mentioned the difficulties to read in VR.
E05: There is a lot of text and there is scarce readability in VR. In the end, the amount of text was fine, but because there were three barriers. Introducing highlighting in the text would allow to go through it faster, but additional info is very important [...] You could incorporate some audio feedback. Text is hard to read in VR, you could choose to have it read out loud with a button.
A second issue with the textual explanations is that, while it provides an easy and understandable way to describe the accessibility issue and target group of the barriers, it makes the simulation boring. That defeats the goal of the experience of being a lightweight and playful way of sensitizing people while teaching about architectural barriers.
E02: The target groups and the barriers specifics are unknown (in the scene with animations), while written is more explicit/easy to understand. The boards are boring because you need to read, and you don't want to read in such a setting. [...] I'm conflicted about which representation I prefer. I like the embellished ramp because it's more straightforward, but the display was not self-explanatory. The text is useful, but tedious to read."
Conclusion: the system of using textual boards to explain concepts, introduce details, and confirm previous understanding is important to support the learning experience. Making sure that no wrong information is conveyed by the animations and that relevant details are clear is very important, but reading in VR carries issues that need to be taken into account and addressed to avoid encumbering the experience.
(Sug: Developers in the future, when coming to the introduction of written paragraphs in an educational simulation, must be mindful of text formatting, length, and provision of alternatives.)

T2.2: Effects – This theme discusses how the designed embellishments and animations impacted the players' ability to pay attention to the desired events happening during the first scene of the experience.
The effects include the barriers highlighting, the particle system triggered

when interacting with the barriers, and the animations displaying possible solutions. The general feedback on the effects suggests that they were very visible and caught a lot of attention. They were mainly appreciated for the visual appeal and playfulness they added to the scene.
E02: The effects stood out and were surprising since I didn't know what kind of consequences would be triggered [...] The animations give a game-like feeling and make it easier to get the user's attention, feeling more like playing a game [...] I think the first version is more appealing than the boards.
E02: The museum style with the boards is like an educational thing. The animation one is more about interacting with the objects. The boards one is static, while the animations are more dynamic, it has more of a game feeling, it's playful.
On the other hand, experts were concerned about the effects being too predominant in case of more architectural barriers displayed during the simulation.
E01: In case of more barriers, the embellishments would be too much, while the last simulation would be ok. [...] In case of more barriers, it would be better to remove some highlighting, there's too much glitter. Maybe that's because glitter is not attractive or beautiful in my opinion; it's a personal preference.
It was suggested that the appropriateness of the chosen effects is linked to the developed application and desired target group. Different, more subtle embellishments should be considered if playfulness should be contained.
E05: The appropriateness depends on the target group. The effects are fine to get a lot of attention, for the general population, but for more of a serious/business context, something different and less playful should be used, like a spotlight effect.
Conclusion: the presence and the chosen aesthetic of the effects and animations have a relevant impact on the player's predisposition and feelings toward the simulation, setting the tone for a playful and interesting experience.

T2.2.1: Explosions – This sub-theme highlights how the explosive effect played simultaneously to the animation can either guide or distract the players' focus from the desired target depending on its implementation. The explosion triggered alongside the animation when the player interacts with the barriers was the least appreciated and most problematic of the effects. Its predominance on the events happening in the scene made it the most distracting and upsetting component of the simulation with mostly negative feedback and little to no appreciation. Three out of five experts agree that the explosion captures all the player's attention distracting them from the animation that displays the solution to the architectural barrier.

E02: The explosion distracts from the solution animation. It's the most intrusive effect; it surprises you and catches all the attention. The animation and the other effects are more subtle. Maybe you should separate them.
E04: The effects activated when clicking, the lighting explosion is confusing, it caught a lot of my attention on the sparkles other than the object and its animation. In fact, it took me a few attempts to actually get what was happening. I think the sparkles are distracting [...] I would reduce the sparkles of the explosion.
The remaining two experts didn't advocate in favour of the explosive effect and maintained a more general stance suggesting that glitter and sparkles should be reduced, mindful also of health issues they might create.
E03: I would put less sparkles. They're not good for visually impaired users and epileptic people. Pulsating light could be used instead.
[Sugg: Therefore, more subtle effects should be preferred because of their more discrete impact on the player's attention toward the architectural barriers and their solutions.]
Furthermore, the explosion has the positive effect of suggesting that something is happening as a consequence of the interaction and, therefore should be maintained. On the other end, especially if the player positions themselves too close to the target, the current version of the effect occupies most of the player's field of view preventing them from focusing on the animation. A correlation exists between the relative sizes of the architectural barriers, the modifications necessary to solve the accessibility issues, and the effects triggered alongside the animation in case it is concentrated and very visible. In fact, if the effect is small in proportion to the barrier and the solution is clearly distinguishable from the previous state, like in the staircase/ramp example, the distracting effect of the explosion is contained. Otherwise, the explosive effect is predominant and other events might be lost.
E04: The sparkles suggest that something is happening, but they are distracting. The sparkles are less of a problem for the stairs because there is a more obvious change.
<u>Conclusion</u>: the hierarchy of simultaneous effects greatly impacts the player's ability to concentrate on the desired features of the experience. Very visible and concentrated effects have a distracting effect on the players' concentration on other events.

T2.2.2: Animations (Speed, Precision) – This sub-theme shows which aspects of the animations positively or negatively affect the players'

attention and ability to notice the changes in the barriers that show the solution instead of the issue.
The characteristics of the designed animations influence the ability of the player to identify the changes displayed for each barrier. The animation created for the display included a rotational motion together with a vertical jump and it was not received well because too fast and articulated for a small change between before and after. On the other hand, the ramp appearance from the staircase in a sliding motion was appreciated because slower, simpler, and applied to a bigger object.
E02: For the first barrier, I only saw the explosion and didn't notice the solution. It was too fast. You could slow it down and move the explosion from the centre to the side [...] The ramp was really nice [...] For the shrinking slower would be better, like the ramp.
A second feature of the animations that impacts the players' attention on the message conveyed is the precision of the displayed solution. Depending on the application's target group, the required precision in the presented solution changes. Inaccurate details can be misleading and distracting in the context of architecture studies, while to increase awareness among the general population less strictness on details is required.
Expert E01 is architecture professor at KIT and states:
I'm disturbed by the solution coming up, in fact the solution should be more precise like the ramp that has better readability [...] More detailed solutions would be better for architecture students; for the general population less strict is fine. For example, the ramp reaches the second step and must be 6% at most. Details matter for architects.
<u>Conclusion</u>: the animation that displays a solution should be simple enough to allow the player to recognize the changes before and after the movement. Additionally, the precision of the displayed outcome should be sufficient, given the target group, to correctly present all the necessary details the player should focus on.

T2.3: Setup – This theme discusses which aspects of the simulation setup and ease of use help or hinder the player when immersing in the experience and completing tasks.
On the general aspects of the experience setup, it was reported that sitting and standing give different impressions. Sitting might remind of being in a wheelchair, which is not desired, but also feels safer, especially if the user is not used to VR.
E02: Standing could feel more realistic, but the chair feels more safe, you're more grounded to reality. Maybe because I'm not too experienced with VR.
During the questioning emerged that the mounted headset chosen for this

study has issues that obstacle the players during the experience. The weight of the headset and the impossibility of wearing glasses hinder the simulation accessibility.
E04: The headset has a lot of weight.
E02: I think the second part is appropriate and understandable, but a different way of explaining, like audio, could improve the experience. In fact, reading without my glasses was difficult. Observing the animation while listening to the audio would be better.
Conclusion: Any element of the setup that induces discomfort, provokes insecurity, or creates an obstacle for the player adds to their mental load, consequently preventing their full attention from being on the desired aspects of the simulation throughout the experience.

T2.3.1: Commands (Interaction, Navigation) – This sub-theme describes how the choice of interaction and navigation commands can improve the player's immersion or negatively affect their cognitive load. The complexity of commands in the VR simulation affects the players' attention. Intuitive and easy-to-grasp commands facilitate the players' navigation and interaction with the virtual world, enabling them to fully focus on the experience. On the contrary, if the control system is too complex and articulated, users may find themselves preoccupied with trying to master it during the experience. This distraction disrupts their immersion, as they are unable to fully invest their attention in the simulation's content and objectives.
E04: The moving is on the left only, while on the right would be more intuitive. VR has an impact on new people. Getting confident with VR controls takes some of the focus. The tutorial was good and useful indeed.
The participants appreciated the simplicity of the commands required for this simulation and the presence of the tutorial at the beginning of the experience. This combination allowed them to try and master the necessary mechanics before starting the main part of the simulation, where their attention should not be distracted by figuring out the controls.
E05: The setup is really easy and self-explanatory. The interactions are easy, there's few functions to learn; it's good for people not used to VR.
Conclusion: users new to VR are the ones that benefit the most from simple and straightforward controls. Easy and self-explanatory commands, together with a space during the experience to familiarize with them, have a positive impact on the players' ability to focus on the experience's objectives and should be a priority.

T2.3.1.1: Interaction – Concerning the commands necessary to

interact with the architectural barriers in the simulation, big selectable areas were preferred. Aiming at the interactable objects to trigger events should't be a concern during the experience because the players' focus should remain on the barriers displayed and message conveyed.
E04: It's tricky to catch the items like the menu button and the book. Bigger clickable containers could be used because a lot of focus goes into hitting the book right [...] I would add a bigger padding to hit the menu button or the book, a bigger clickable area.
<u>Conclusion</u>: Interacting with the simulation's objects and menu buttons should be simple and straightforward to avoid distracting the players from the experience.

T2.3.1.2: Navigation – Concerning the commands necessary to navigate the virtual environment, continuous movement and rotation were chosen to reduce as much as possible the overhead needed to understand different mechanisms. The main concern was motion sickness, that can be caused by VR especially to people that are not used to it. With the continuous movement motion system, the avatar moves forward in the direction the player is looking at, preventing sudden changes in direction. Additionally, the player's speed was adjusted to avoid rapid accelerations that could increase the chances of motion sickness.
None of the participants, included the ones new to VR, suffered from motion sickness during the experience, suggesting that the chosen settings were suitable for the goal and comfortable for the players. Nevertheless, Expert 5, specialized in VR simulations of visual impairments, suggested considering other motion systems like teleportation and snap turning to facilitate moving around. Main reason for the suggestion was the safety concern due to the cable connection between the headset and the computer streaming the experience.
E05: On the kind of controls, it's cool to be able to switch rotation (she refers to snap rotation), especially having a cable continuous turn is risky [...] A better way to "jump" between the barriers could be added, to be able to go back. Teleportation walking for example.
<u>Conclusion</u>: multiple navigation systems can be implemented in VR and people familiar with simulations might have favourites due to previous experiences. Nevertheless, simplicity of commands should be the goal because it showed to be the most important and appreciated feature.

T3: Comprehension – This category investigates the elements and factors that affect the understandability of the messages conveyed during the simulation and the efficacy of the delivery means.

T3.1: Solutions – This theme explores the effectiveness and limitations of using animations as a tool to educate about accessibility issues possible solutions in public buildings.
Expert 01 is architecture professor at KIT and highlights the positive impact displaying modifications to the virtual environment to solve accessibility issues can have on architecture students.
E01: I's good to see a solution. It's easy for architecture students to become problem detectors, but solutions are difficult to find and create fear [..] (the experience) puts me in the mood of having my students working on it to focus on solution finding. Lighting and acoustics can be difficult though. Showing barriers is not enough, to find and show different possible solutions for teaching purposes in architecture is good.
The animations positively contribute to the players understanding of the presented accessibility problems and help them visualize possible alterations of the space that would make it more inclusive.
E05: The animations were helpful to understand, and the text was good feedback, but it's way better feedback to actually see the change [...] it's good direct feedback to display the solution.
Conclusion: visually showing the environment changes to solve accessibility issues has a positive impact on the players' ability to recognise the preexisting problems and understand the consequences of the modifications.

T3.1.1 : Comparisons – This sub-theme illustrates the important role comparisons have in the process of understanding the displayed accessibility issues and solutions.
The need for comparisons was a recurrent topic when debating the understandability of the animations alone, without the provision of additional insight in textual or other forms.
The advice of introducing direct comparisons between the before and after state of each barrier, and the suggestion of providing a way to compare different solutions for each issue indicate that being able to accurately examine differences is seen as an important tool for understanding the events when a direct explanation is not provided.
E03: You could show both light conditions contemporarily, like using a newspaper with different lighting. This way you can directly compare the settings [...] You could choose which ramp to show when clicking to allow comparing solutions.
Sometimes the size of the changes necessary to resolve an accessibility

issue are contained with respect to the scale of the objects undergoing modifications. It is not unusual that small alterations can determine whether a design choice fosters or limits inclusivity but said modifications in form of animations might be lost on the player during the experience.
E02: On the first and second barrier, the difference is not noticeable enough. The solution is not noticeable enough, maybe because I was not wearing my glasses, but I missed the solution [. . .] The ramp is more understandable and intuitive, but the display is not that intuitive and understandable. You have no comparison with a person to see the problem. Not everyone knows or recognizes the problem, previous knowledge is needed.
<u>Conclusion</u>: allowing comparisons between the states of the barriers and the unaltered environment boosts the understandability of the displayed solutions because it makes also small changes easier to detect.

T3.1.2 : Background Information – This sub-theme describes the impact of background knowledge on the understandability of the displayed architectural barriers and corresponding solutions.
The need for background knowledge in order to autonomously understand the displayed issues and solutions is a relevant topic in the evaluation of the animations' understandability.
Small changes might be more difficult to spot for inexperienced users that are not familiar with the variety of accessibility issues present in common public spaces.
Additionally, the experts share the feeling that visual impairment is more difficult to imagine and understand compared to other disabilities.
E05: For example, with the book I'm not sure if people with no background would get it without the explanation. It is harder to understand when visual impairment is the target group. People cannot get a picture of the disability in their head; the individuality of the problems is not common knowledge, and more info is needed.
This indicates that including visual disabilities in this kind of simulations can help in sensitizing about issues that are less commonly noticed. On the other hand, particular attention needs to be paid to avoid displaying confusing concepts that lack sufficient explanations to be understood.
E05: For visual impairments you could have more examples. For example, you cannot recognize other people in the darkness. You could add more things to display.
<u>Conclusion</u>: solutions' animations are not sufficiently understandable on their own when the changes are small or less commonly known disabilities are involved. If users' background knowledge is not a given, additional

explanations need to be introduced to complement the players' understanding of the critical concepts.

T3.1.3 Objects – This sub-theme shows how the selection of objects used to illustrate accessibility issues and solutions can influence the users' perception and understanding of the underlying accessibility issues.
Choosing suitable objects to highlight accessibility limitations is very important to avoid conveying the wrong message or minimizing the problem. In the case of this study, both expert 05 and 02 observed that the choice of the book in the cafeteria environment was not appropriate to sensitize bout the insufficient lighting of the room.
E05: Showing the book as solution, people would think that the solution is to just use something with retro illumination. With the book to representation of the barrier, people might not get the size and all the sides of the problem.
E02: For the light issue, I would change the book, which is not too appropriate in a cafeteria. You could use a meal on a plate instead: with poor light you don't see the details on the food.
<u>Conclusion</u>: objects used as tools to highlight accessibility issues need to be carefully chosen to avoid trivializing or distorting the concepts conveyed.

T3.2: Explanations – This theme explains the contribution textual explanations have on the participants' understanding of the illustrated topics.
The experts feedback is not uniform on the amount of details that should be contained in the explanations to consider them informative. Experts 02, 04 and 05 agree that the provided explanations have a positive impact on the users and their presence is very important. According to them the boards content is insightful, suitable also for users not familiar with accessibility issues, and satisfactory in terms of details contained. On the other hand, Experts 01 and 03 indicated that more information should be contained to guarantee a more complete understanding of the issues and solutions.
E02: The explanation was useful to understand the obstacle and the target group better. [...] The target groups and the barriers specifics are unknown with the animations, while written is more explicit/easy to understand.
Additionally, the explanations could introduce universal design concepts to show the wide impact accessibility issues have on the population.
E02: You could explain who benefits from the solution, the target group, not only disabled, but also children and injured people. This way you don't make it only about disabled people. You can show and describe the impact on everyone.
<u>Conclusion</u>: the amount of detail contained in the explanatory boards needs to

be tailored to the application target group. Sensitizing the general population or creating a tool to educate about accessible design guidelines would require different level of detail in the information boards. Nevertheless, the explanations should remain concise and only convey the most important points to avoid boring and tiring the participants with excessive lengths of text to read.

T3.3: Merging – This theme discusses how merging different communication tools, meaning the visual representation of issues and solutions and the textual explanations of the concepts, can concur to create a comprehensive and solid understanding of the topic.
The concept of separating the visual and textual explanation techniques was used in this study to identify the contributions to understanding brought separately by the two components. As expected, the experts reached the conclusion that a version of the experience that combines both visual and textual explanations would constitute an improvement with respect to the current version of the prototype.
E01: Merging would be an improvement. If the difference of the solution might be lost, the text addition would help.
<u>Conclusion</u>: merging different communication tools is believed to improve the completeness and robustness of the user's the overall understanding.

> **T3.3.1: Simultaneous Merging** – this sub-theme explores the idea of merging visual and textual explanations in a single experience, introducing both kind of cues at the same time.
> A first technique to merge the animated solutions and the textual explanations would be to keep the written details as reinforcement of the delivered information but placing them in the virtual space superimposing the architectural barriers.
> E03: I'd like more information on the animation. [. . .] You could highlight on the ramp what is important about it, like the curbs, the handrails etc. [. . .] Provided information could be more, notes could be taken specifically on the ramp to show what exactly the text refers to, like the handrails prosecute further than the last step, etc. That would create a more precise solution.
> The simultaneous presence of the animation and the explanation allow the player to trigger the appearance of the solution multiple times while inspecting the points mentioned in the text. Being able to consolidate one's comprehension by triggering the animation more than once while reading the details on it could be beneficial to the player's understanding of the desired topics.
> E05: The boards have really good explanations, they're good reinforcement. But it would be nice to combine them: I would have tested the

animation again when reading the explanations.
Conclusion: simultaneously combining animations of the solutions and textual explanations of the details can strengthen the players' understanding of the conveyed message.

T3.3.2 : Hierarchical Merging – this sub-theme discusses the concept of merging visual and textual explanations in a single experience but introducing the cues in sequence, allowing the player to think on their own before being prompted with the explanation.
The second merging technique allows the users to autonomously think about what they're seeing, formulating hypothesis, and understanding the concepts independently before correcting or confirming their assumptions and introducing additional details with textual explanations.
E04: I saw the experiences in a level way. As a sequence. It is interesting to have the combination, I saw them as a single thing. It's good to have no comment at first to think and understand autonomously. It's possible to not recognize the change from the animation and then get the explanation afterward and realize the change and understand.
Making the information obtainable on request instead of constantly available allows the player to proceed at their own speed, getting the information quickly if desired, but allowing for independent processing time if desired.
E02: When seeing the solution, you could have an info button to click and get an explanation in audio or text format if it's not clear.
E03: For example, you could give a hint of the problem, something such as "height", "light", "accessibility", and more explanation at a second level with details.
Conclusion: cascading the solutions' animations and textual explanations of details create a separation that allows the player for independent reasoning and understanding if desired, while still providing the clarifications as soon as needed.

T3.4: Closure – This theme discusses how closure of a series of events is received by experts when experiencing the simulation.
The expects highlighted how the devised effects were not sufficient to convey when a series of events was concluded and no additional events should be expected resulting in confusion.
E03: I found the sparkles in the display confusing because I expected more, and I did not understand if more was supposed to happen. For example, you can make it green to show that a task is finished. [. . .] Colour feedback is missing, for example you could turn the colour to green when something is completed.

Conclusion: a mechanism should be devised to suggest that a series of events is concluded and the player can move to the next step of the experience like looking for the successive architectural barrier.

T3.5: Tasks – This theme highlights how guidance during the experience is received by the participants and its contribution to comprehension.
The Highlighting was indeed helpful when the barriers needed to be distinguished from the background environment, but a lack of wider tasks was spotted by the participants. Confusion was due to the absence of explicit guidance during the experience and more redundancy in explaining the goal of the simulation would have been appreciated.
E04: It's less important, but I would specify that there are three items to find. It's good to know as a participant that there's another one. Having more directions on what to do would be an improvement.
E05: Also, telling the goal of the experience and giving more info on the desired outcome would be better. Not knowing during the simulation makes understanding harder. Knowing the goal helps understanding what to look for.
E03: You could have user cases to have the user going through a procedure task. As an improvement having a task would be better. You do the task, and the barriers appear while you do it. It would work to get people into place with a task and then activate the barriers on the way.
Conclusion: the goal of this prototype was to analyse the effect specific components of the simulation have on the players, but a set of goals and clear reminders during the experience would be a necessary addition to direct the user toward the targets when they're not in sight.

T4: Reflection – This category discusses the factors that contribute and stimulate the players process of reviewing concepts, retaining information, and pondering on the concepts displayed during the experience.

T4.1: Separation – This theme discusses how the introduction of a delay between the presentation of the solutions in the animated form and the written feedback of concepts and additional details as a tool to foster autonomous thinking.
The second expert suggests how the effort necessary to understand what is shown is a catalyst for understanding and personal reflection.
E02: It would also be good in a merged version to have time to imagine and think about the barrier. The "anstrengung", the effort to understand the barrier is important.
By delaying the explanations, the experience becomes more engaging and thought-provoking. This approach allows the players to formulate hypothesis

before receiving the textual feedback, fostering a deeper understanding of the concepts (see). As a result, the reasoning behind each barrier becomes an integral part of the educational experience.

E04: The dynamic is interesting, you see the current state, you see the change, you make an assumption that is nice to reinforce with the text afterwards to get confirmation. The brain starts thinking when you see the change but don't have the explanation right away. [...] It's good to have changes without comment and get the explanation later; you have more space to recognize the changes without being prompted with an explanation right away.

Conclusion: even though the prompt availability of information creates a smoother experience that is easier to follow, the presence of delays stimulates players to autonomously understand the concepts displayed. Layering successive steps of understanding is beneficial to the overall comprehension of the desired notions and supports future elaboration of the ideas. Therefore, in the context of an educational tool (see), reflection and autonomous thinking should not be entirely trod for smoothness and speed.

T4.2: Generalisation – This theme describes how the process of forming general concepts, principles, or rules based on specific instances or observations was fostered or hindered by the components of this study's simulation.

Being shown instances of architectural barriers can lead the players to recognise similar issues in the same virtual environment or in real public spaces they frequent.

E01: The height problem causes sadness, but also social problem if for example a table is not adapt to someone.

Providing specific information about the addressed impairments or explicitly categorizing the architectural barriers according to their targeted disabilities can help players investigate the virtual space looking for possible issues and formulate scenarios that involve the different disabilities in the surroundings.

E05: Different target groups of barriers could be highlighted better. While looking around with a target group in mind you can imagine other problems and solutions.

A limitation of the animations could be that they show a single item as example of bad design and poor accessibility choices. This may hinder the players' ability to generalise concepts and recognise similar issues across different objects of comparable nature. On the other hand, textual explanations do not present the player with prepared images of what is described. The absence of specific illustrations fosters a more natural process of generalisation since players are required to imagine the described scenarios.

E05: I got the impression that for the animated version you get the feeling "this specific thing is a problem", while with the boards explaining the background you can generalize more and extend it to other objects in the environment.

This is the effect of the background info.
Conclusion: while animations can illustrate detailed solutions without extensive descriptions, textual explanations encourage generalisation because they do not depict specific items. Balancing the stimulation of generalisation with the provision of examples for anecdotal understanding presents a challenging task, yet both objectives are essential to foster long-term reflection.

T4.3: Memory – This theme examines the factors that contribute to the commitment of the newly acquired knowledge and understanding to memory following the simulation experience.
The first expert is architecture professor KIT and suggests that Virtual Reality (VR) simulations offer advantages with respect to traditional educational material like books or slides. By providing an immersive and interactive experience, users engage with the content in a more dynamic and memorable way. Interactivity and active manipulation enhance comprehension and retention of concepts, providing a valuable educational tool.
E01: On the general concept and the barriers explanation you remember more after VR than reading on books and slides.
The length of the experience is a determinant component that affects the player's ability to recall both what they observed and the explanations they were given. In case of longer simulations, more information could be conveyed, but details might be forgotten in favour of a better comprehensive understanding.
E05: It's good the amount of time needed for the experience. It's good to be able to remember all.
Retaining all instructions given at the beginning of the simulation and recalling them throughout the entire experience poses a challenge for participants since the simulation details are unknown. While the initial summary was appreciated, crucial information to successfully complete the simulation may be forgotten and should be available for consultation at later stages.
E05: The initial instructions at the beginning of the simulation on what to do are difficult to remember from the initial menu, like the number of barriers.
An end summary of the architectural barriers presented during the simulation could refresh the players' memory of what they observed and aid recollection the concepts. Presenting a condensed version of the experience could facilitate a rapid review of the key points enhancing the players' understanding and improving retention.
E03: You could add a game effect in the tool at the end with tasks, barriers, current solution, and the improved solution without the barriers. With current solution I mean the current way of doing stuff, like where the ramp is missing, the alternative to leave the building is through the sliding doors and the outside slope.

Conclusion: aiding the memorisation of the concepts and the retention of information is crucial in creating an effective tool to sensitise about architectural barriers. Available reminders facilitate the players recollection of the key concepts, and a suitable experience length guarantees adequate memorisation of all examples.

T4.4: Focus Shift – This theme illustrates how the simulation shifts the participants focus from dwelling on the limitations posed by the architectural barriers to the possibilities presented by the obstacles' solutions.
Displaying solutions to accessibility issues directs the participants attention away from the limitations induced by the architectural barriers and focuses on the importance of solution finding.
Thinking about the difficulty to fit a solution in a preexisting public space the first expert, an architecture professor at KIT, emphasizes that stopping at the architectural barrier is not sufficient. Introducing and displaying solutions allows moving from issues identification to critical thinking and problem-solving, fostering a solution-oriented and proactive mindset.
E01: I's good to see a solution. It's easy for architecture students to become problem detectors, but solutions are difficult to find and create fear. Showing possible solutions is important but must be accurate. [...] It puts me in the mood of having my students working on it to focus on solution finding. Lighting and acoustics can be difficult though. Barrier is not enough, find and show different possible solutions for teaching purposes in architecture is important.
Displaying solutions can be a way of highlighting issues that were previously unnoticed. Displaying the new accessible environment allow players to recognise the changes and reflect on the other occasions where architectural barriers of similar nature went unnoticed.
E05: I didn't notice the room was so dark before interacting with the book, but after the hint it's impossible to miss.
Conclusion: the technique of displaying solutions to architectural barriers successfully redirected the participants' focus from the constraints introduced by the architectural barriers for people with disabilities to the importance of creating an environment equally accessible to all users.

T5: Completeness – This category collects the themes representing aspects of the simulation that could be improved or integrated to make it more complete and fulfilling.
During the interviews suggestions emerged on features that should be introduced or modified to improve the experience. This category differs from the previous ones because the collected feedback concerns components that are not present in the prototype or greatly differ from the ones presented. Experts discuss advantages and

disadvantages of mechanisms they did not experience but imagined as integrations or modifications.
Conclusion: the content reported in this section collects ideas of features introduction or modifications that the experts would consider improvements or concerns therefore highlighting week spots of the experience and its developments. The feedback analysed should be interpreted considering the features discussed were not experienced by the participants.

T5.1: Audio – This theme describes how audio explanations and signals are relevant to the experience and could be introduced to improve the simulation. This study focused on the visual means of conveying information (see 2.3). Auditory feedback was not a predominant embellishment in the simulation and went often unnoticed by the participant, possibly also due to the contained volume. Feedback was given on the lack of acoustic cues and explanations suggesting that they are expected to play a relevant role in this kind of experiences.
Conclusion: the request for increased acoustic signals and additional auditory explanations suggests that those aspects were perceived as missing and therefore their features should be investigated prior introduction in refined versions of this prototype.

T5.1.1: Explanations – This sub-theme details how auditory explanations would improve the fruition of the experience.
Four experts out of five spontaneously suggested to introduce a loud reading option for the textual explanations. Allowing players to listen to the descriptions instead of reading them in the playful context of the simulation with the limitations introduced by Virtual Reality would improve the comfort and adaptability of the experience.
E02: I think the second part is appropriate and understandable, but a different way of explaining, like audio, could improve the experience. In fact, reading without my glasses was difficult. Observing the animation while listening to the audio would be better.
E05: You could incorporate some audio feedback. Text is hard to read in VR, you could choose to have it read out loud with a button.
E03: Also in the tutorial a audio tutorial could be provided, to have audio and visual and haptic feedback. [...] The audio description should be added everywhere.
Conclusion: given the unanimity of the participants in suggesting audio explanations as improvements, I assume that the readability of the boards was very low and an alternative should be provided to make the experience smoother and more accessible. Audio registrations could be a valuable tool but, since they can be perceived as annoying, other options

should be investigated.

T5.1.2: Effects – This sub-theme describes how additional acoustic effects and feedback could be introduced to improve the simulation experience.
Three out of five experts suggested that auditory effects implemented in the simulation were unnoticeable or perceived as absent and state that they would have been a relevant feature in supporting understanding.
E04: I didn't notice any sound effect, but it would have helped.
E03: The display animation is difficult to spot, some audio could be used to suggest that the display is shrinking and going down.
Conclusion: introducing more noticeable sound effects alongside events in the simulation would constitute an improvement and facilitate understanding.

T5.2: Disability Simulations – This theme discusses the thoughts concerning the introduction of disability simulation features in the experience.
The approach of simulating disabilities to raise awareness and foster understanding through Virtual Reality (VR) simulations was not employed in this study. Exposing participants to the virtual environment with simulated impairments could inadvertently reinforce stereotypes and foster pity (see 2.?), ultimately undermining the effectiveness of the experience.
Simulating disabilities to improve understanding of the architectural barriers is still considered a valuable tool and was brought up during the questioning as a way to improve the experience in different variations.
Conclusion: the feedback on disability simulations reflects the participants' field of expertise and work experience. In this section the statements will be analysed with the goal of highlighting issues and suggestions for improvement of the prototype without modifying the fundamental principles of this study (see 2.).

T5.2.1: Perspective Taking – This sub-theme discusses the concept of adopting the viewpoint of people with disabilities for an experience to raise awareness about architectural barriers.
Experts 03 and 05 work with disability simulations mostly in the context of visual impairments. They suggest that taking the prospective of disabled users would improve the experience by providing a comparison. The disabilities targeted in this prototype are motor and visual impairments, which they suggest could be respectively simulated by modifying the user's height and by virtually blurring their vision.
E03: You could switch the user from normal to in a wheelchair to visually impaired, for example you could blurry the vision.

E05: You could try the experience both sitting and standing, to get a better understanding of the problem, to take the perspective of different users.
Expert 02 suggests that experimenting the perspective of visually impaired or wheelchair users would allow to directly feel the issues caused by the architectural barriers fostering better understanding.
E02: You could make the avatar in the simulation smaller to have a direct feeling of the problem, the screen. Or use dark glasses for the light.
Conclusion: disability simulations are still believed to be valid tools to foster understanding and increase awareness on architectural barriers and accessibility. Alternative approaches should be sought and further investigated to provide alternatives and favour inclusion.

T5.2.2: Struggle Simulation – This sub-theme discusses the introduction of struggle with architectural barriers as an improvement of the simulation prototype.
The concept of simulating the distress caused by architectural barriers was brought up multiple times as an improvement possibility for the prototype. Possibilities suggest either displaying another avatar struggling with the issues or having the player directly experience the hardships a disabled person would face when interacting with the barriers.
E02: It would touch the user more seeing a person struggling with the barrier, it would be less theoretical. [...] Seeing someone struggling touches people more directly and prompts reflection, a stronger reaction. You would have a bigger reflective impact.
E05: The height in the scene, like sitting, close to a wheelchair was useful to see the improvement with the display device. I saw the improvement because I was sitting. You could simulate more the struggle.
Conclusion: Facing the limitations architectural barriers can cause without the experience disabled people have would produce a counterproductive form of reflection. The goal of the experience was for participants to not dwell on the restrictions created by the architectural barriers but focus instead on the solutions that could be implemented to create a barrier free environment. Expert 05 feedback can be interpreted in a different key, suggesting modifications beneficial to the prototype without changing its nature and principles. Since the improvement in the display device accessibility was noticeable only because the participant was sitting, designing solutions to make the modifications easily recognisable also from standing would improve the experience understandability without compromising its principles.

T5.2.3: Sitting Position – This sub-theme highlights the consequences of sitting on a chair during the simulation experience in connection with disability simulations.
Expert 01 brings to attention how sitting in a chair during the experience necessarily reminds them of being in a wheelchair. Sitting during the simulation was a possibility provided for the player's comfort and safety, but the risk of mistaking the position for the simulation of a wheelchair was a concern from the beginning. Expert 01 confirms that in the context of architectural barriers awareness, sitting is necessarily linked in the participant's mind to being in a wheelchair.
E01: On the concept and the barriers explanation, sitting makes feel like disabled which is not intentional. Sitting means being on a wheelchair.
Conclusion: the possibility for participants to sit during the experience was detrimental and counterproductive to the study's goal of not simulating disabilities. The elimination of the option should be considered, and alternatives should be investigated.

T5.3: More Barriers – this theme discusses the suggestions of incrementing the number of displayed barriers during the simulation.
Introducing additional architectural barriers was a recurring suggestion. All the problems present in the real cafeteria could be displayed and additional scenarios could be introduced as use cases of common issues in public spaces. Players could also be involved in the process of formulating solutions to solve the presented issues.
E03: You could dim everything but the barriers, show all the problems in the cafeteria, that are so many and explain or ask the player what to change. [. . .] For the doors toward the stairs, how if they were closed? How could you open them? It could be another barrier.
More disabilities could be included, and the architectural barriers could be divided according to their target group to show recurring patterns and issues without confusing the players.
E05: For visual impairments you could have more examples. For example, you cannot recognize other people in the darkness. You could add more things to display.
E01: The simulation could be theme based, to not overlook other disabilities other than wheelchair users.
Conclusion: incrementing the number of targeted disabilities and adding architectural barriers could improve the completeness of the experience and provide more information. Nevertheless, the length of the experience (see T4.3) and the mount of embellishments (see T2.2) should be carefully considered to avoid overwhelming the participants.

T5.3.1: Crowd – this sub-theme discusses the introduction of people in the virtual cafeteria as a barrier for people with disabilities.
This prototype did not introduce crowds among the barriers because it was deemed beyond the scope of the project (see). Nevertheless, the introduction of people within the cafeteria was brought up as a possible integration to improve the completeness of the prototype.
Expert 01 is an architecture professor at KIT with particular interest in accessible design. They suggested to introduce the crowd to make the virtual environment more realistic while introducing a barrier that is often overlooked.
E01: The simulation could be theme based, to not overlook other disabilities other than wheelchair users. You could diversify the barriers more and give the impression of a crowded area.
E01: The space was empty, the crowd is missing, in fact the crowd can be part of the barriers.
Conclusion: introducing people in the simulation would probably make the environment more realistic and it would sensitise participants about the obstacles created by high people density. On the other hand, introducing crowds in the environment might be overwhelming and distracting for the participants while making the space harder to navigated because of the reduced visibility in the unknown space. The goal of the simulation is not to have players struggle with finding their way within the virtual cafeteria, but to concentrate on the presented architectural barriers instead.

T5.4: Adaptation – This theme explores the enhancement of the simulation's flexibility to better adapt to the participants preferences as a way of improving the experience.
The experience should be suitable for all players. Expert 03 suggests that the experience could be personalised during the introduction by defining some settings and preferences.
E03: The idea is of inclusive digitalization, where you adapt the system to the user. In the tutorial you can ask the user for how they would prefer it. You can ask in the tutorial for preference on the boards positioning.
The textual explanations placement could be adaptive to the player's position when they reach the architectural barrier. Additionally, the possibility of hiding the details with a button would allow the player to not be distracted during the exploration and have a clear field of view when desired.
E03: For the boards experience, the player is too close to the barrier. You could make board positioning adaptive to the user position, like for the menu button. You could use relative distance and positioning and you can allow to

hide the boards.
Conclusion: adapting some simulation features to the player would improve the simulation making it more flexible and fitting on the player's behaviour. On the other hand, the additional settings and preferences would increase the length of the experience and require the player to make decisions in an unfamiliar situation. The user's attention and energy should be on the architectural barriers, core topic of the experience, and keeping other aspects simple should be a priority (see 2.3.1).

T6: Employment – This category discusses the prototype's concept, validity and future expansions as a tool to educate and raise awareness about architectural barriers and buildings accessibility.

T6.1: Appropriateness – This theme discusses the features that make the prototype suitable and useful for future developments as an educational and awareness tool.
The general concept of the application was appreciated by the experts that all have a background in accessibility related fields. The focus on solutions and the simplicity of the commands were the most appreciated features, while the importance of explanations and details was highly regarded.
E03: I like the overall idea. At a first thought it's really nice and useful to sensitize people on the topic. It's good to show solutions, to interact and gain knowledge. [. . .] There's a lot of potential.
Conclusion: the basic features and principles of the prototype proved to be appropriate in the context of a tool to raise awareness and educate about accessibility in public spaces.

T6.2: Applications – This theme discusses the variations in applications that can be built from this simulation prototype and the demarcating factors relevant for the different tools that can be created.
Different evolutions of the prototype could lead to develop tools to increase awareness on accessibility issues in public spaces or educate about possible solutions. The experts mentioned possible applications and the feedback led me to identify three main categories.
A first target group for further developments of the prototype and its concepts could be the general population. With the development of a tool to raise awareness about accessibility issues in everyday life, the concepts of this study could be used within or outside the scope of the university.
A second application could be as an educational tool for architecture and building design students. The prototype could be expanded to contain more barriers and precise solutions to teach about regulations and facilitate the process of solutions ideation.

A third option would be to create a training tool to inform the personnel that works with disabled people. Specific features could be introduced to provide specialised insight depending on the environment to make workers more aware of the issues and good practice examples.

The experts feedback was heterogeneous, but each participant reported imagining possible developments and applications, both within or outside the university environment.

E01: It puts me in the mood of having my students working on it to focus on solution finding.

E02: Yes, not the schoolish style, but a mixture could be useful to raise awareness on what are the barriers. On a specific disability or to use it as a learning tool for people working with disabled people or not to get more information.

E03: For training reasons and sensibilization for students, yes, it has nice features. You can highlight the barriers and make the player find or choose solutions while learning about regulations also outside KIT, like the "Rathause group". You can use it to actually change a place trying options to see if they're actually accessible with VR. [...] You can also set up a website version without VR of the experience for people to learn about barriers.

E04: I can imagine it used to educate about barriers as well as solutions. It's good to reflect on barriers and solutions, to train on barriers or at least raise awareness.

E05: It could also be used for people designing buildings, to check other barriers on campus to avoid doing the same mistakes. [...] It's interesting for campus teachers and other public places. You could try it in a more public place by displaying a public space and then placing it there to sensitize people. For example, in an administrative building in Karlsruhe you can have the people going there try and see the space from another perspective, to make people think about barriers in their everyday life.

Conclusion: different applications can be envisioned where the principles of this study can contribute to the creation of tools to foster awareness and education on accessibility issues. These diverse possibilities include raising awareness among the general population, educating architecture and building design students, and providing training for personnel working with disabled individuals.

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